AD-A077 900 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7

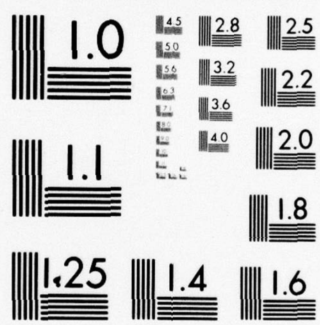
AIRBORNE RADAR APPROACH SYSTEM FLIGHT TEST EXPERIMENT.(U)

OCT 79 L D KING, R J ADAMS DOT-FA79WA-4293

UNCLASSIFIED FAA/RD-79-99 NL

1 OF 2

AD A077900



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF

Report No. FAA RD-79-99

LEVEL II

AIRBORNE RADAR APPROACH SYSTEM

FLIGHT TEST EXPERIMENT

L.D. King

R.J. Adams

October 1979

Final Report

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No. (18) (19) FAA/RD-79-99	2. Government Accession No.	3. Recipient's Catalog No. (12) 128
4. Title and Subtitle (6) AIRBORNE RADAR APPROACH SYSTEM FLIGHT TEST EXPERIMENT,		5. Report Date (11) Oct[redacted]979
		6. Performing Organization Code
		8. Performing Organization Report No.
7. Author(s) (10) Larry D. King [redacted] Richard J. Adams		
9. Performing Organization Name and Address Systems Control, Inc. (Vt) 1801 Page Mill Road Palo Alto, California 94304		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. (15) DOT-FA79WA-4293
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591		13. Type of Report and Period Covered (9) Final Report, Jul - Dec 78
		14. Sponsoring Agency Code

15. Supplementary Notes Prepared by:
Champlain Technology Industries, A Division of Systems Control, Inc. (Vt)
A Subsidiary of Systems Control, Palo Alto, California

16. Abstract

This report presents the results of a comprehensive flight test experiment of an Airborne Radar Approach (ARA) system. The tests were performed within a 60 nautical mile radius of NAFEC in Atlantic City, N.J. The test environment involved three distinct sites: airport, remote and offshore. The test aircraft was a NASA CH53A helicopter manufactured by Sikorsky Aircraft and currently based at NAFEC. ~~The~~ test period was from July 1978 to December 1978. Flight tests for ARA accuracy and procedures development were performed in both skin paint (and passive reflector) and single beacon radar operating modes. The flight test profiles and procedures were developed for the following reasons: 1) to assist the FAA and the user community in developing and certifying standard ARA procedures, associated weather minimums and obstacle clearance requirements; 2) to define and quantify specific ARA system functions and characteristics for use in a Minimum Operational Performance Standards (MOPS) document.

The primary conclusions of this flight test experiment were: the Airborne Radar Approach System tested performed satisfactorily from both an accuracy and an operational viewpoint in the single beacon mode for all three airspace environments; the ARA performance in the skin paint mode showed two significant problems, 1) distinguishing landside targets was quite difficult and could cause operational problems, 2) offshore targets such as oil rigs provide bright returns but are not distinguishable from boats, lighthouses and buoys; the ARA performance in the reflector mode showed that very large reflector cross sections are required to provide positive target identification.

Further flight experiments are planned to evaluate additional radar operating modes such as combined skin paint and beacon modes, and techniques of cockpit display to aid the pilot in his "track keeping" function.

17. Key Words	18. Distribution Statement
Airborne Radar Approach (ARA) Single Beacon Skin Paint Passive Reflector MOPS	This Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	127	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized 389 333

Accession For
NTIS GRA&I
DDC TAB
Unannounced
Justification

By
Distribution/
Availability Codes

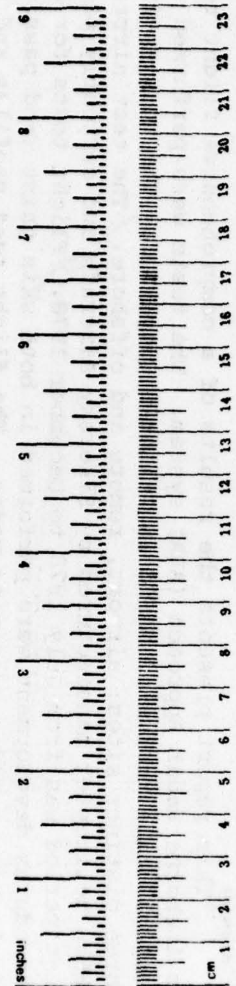
Dist	Avail and/or special
A	

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

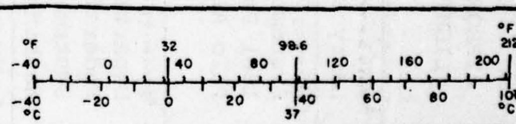
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The Systems Research and Development Service of the Federal Aviation Administration in conjunction with the National Aviation Facilities Experimental Center (NAFEC) has sponsored the Airborne Radar Approach System Flight Test Experiment. This study was an operational and accuracy evaluation of an Airborne Radar Approach (ARA) system. Its purpose was to assess the functional capability and usability of the ARA system so that certification of standard ARA procedures, associated weather minimums and obstacle clearance requirements and system characteristics could be determined. This work was performed by Systems Control, Inc. (Vt), under the contract "Data Reduction and Analysis Support for the Helicopter Operations Program", contract number DOT-FA79WA-4293 Task IV. Primary responsibility for this contract was assigned to the Champlain Technology Industries (CTI) Division.

The FAA technical monitor for this work was Mr. Glen Adams. The program manager was Mr. Robert Pursel of the Approach and Landing Branch (ANA-110) at NAFEC. The principal authors of this document were Mr. L.D. King and Mr. R.J. Adams, both of CTI. The major efforts of flight test coordination, data acquisition, data reduction and analysis were contributed by Mr. L.D. King of CTI. The major contributions for the original ARA test planning came from J.E. Eisele of CTI

The scope of this flight test experiment was somewhat limited in geography but was quite extensive in terms of the amount of data that was collected. The vast amounts of data that had to be recovered and reduced during this test program required a dedicated effort from the entire project team. The following list summarizes the team members, lists individual areas of responsibility and is meant to recongnize the important role and functions performed by each member.

R.E. Ace	(CTI)	-	ARA training concepts
E.H. Bolz	(CTI)	-	Film data recovery, data reduction and statistical processing software development
J.C. Cox	(NAFEC)	-	Photographic data acquisition
J.L. D'Ottavi	(NAFEC)	-	Digital data acquisition recording system development
J.D. Edmonds	(NAFEC)	-	ATC communication coordination
A.L. Gold	(CTI)	-	Engineering graphics support and data presentation
C.W. Mackin	(NAFEC)	-	Project Engineer

J.B. McKinley	(CTI)	-	Data reduction support
B.W. Richards	(CTI)	-	Film data recovery and engineering graphics support and data presentation.

A crucial role in the program was fulfilled by the subject pilots during the flight test program. The pilots were resident experimental pilots at NAFEC in Atlantic City, New Jersey. The four pilots utilized were highly qualified helicopter pilots and offered their utmost in effort and cooperation. The subject pilots involved were as follows:

T.L. Billen	Atlantic City
G. Decker	Atlantic City
R. Lamprecht	Atlantic City
W. Tranter	Atlantic City

Finally, an invaluable and meticulous effort was performed by three important individuals. Ms. K.M. Cinefra, Ms. J.A. Williams and Ms. S.M. Fournier performed the arduous task of typing necessary to produce this document.

Many sincere thanks is extended to each of these individuals without which this report would not have been possible.

Table of Contents

Table of Contents - Continued

Table of Contents - Continued

List of Tables

<u>List of Figures</u>

List of Figures - Continued

ABBREVIATIONS AND ACRONYMS

A/C	-	Aircraft
AGL	-	Above Ground Level
ARA	-	Airborne Radar Approach
ARDA	-	Airborne Radar Directed Approach
ASE	-	Airborne System Error
ATC	-	Air Traffic Control
ATD	-	Along Track Distance
ATE	-	Along Track Error
BCN	-	Beacon
CDC	-	Computer Data Corporation
CDI	-	Course Deviation Indicator
CRT	-	Cathode Ray Tube
dB	-	Decibel
DEG.	-	Degree
EAIR	-	Extended Area Instrumentation Radar
FAF	-	Final Approach Fix
FTE	-	Flight Technical Error
HAA	-	Helicopter Association of America
HDG	-	Heading
HF	-	High Frequency Radio Communications
HSI	-	Horizontal Situation Indicator
IAF	-	Initial Approach Fix
IFR	-	Instrument Flight Rules
ILS	-	Instrument Landing System
IMC	-	Instrument Meteorological Conditions
INS	-	Inertial Navigation System
LAT	-	Latitude
LDE	-	Letdown Error
LON	-	Longitude
LTN-51	-	Litton-51 Inertial Navigation System
MAP	-	Missed Approach Point
MDA	-	Minimum Descent Altitude
MHz	-	Megahertz
MOPS	-	Minimum Operational Performance Standards
NAFEC	-	National Aviation Facilities Experimental Center
NASA	-	National Aeronautics and Space Administration
NCS-31A RNAV	-	Collins Area Navigation System
NDB	-	Non-directional Beacon
nm	-	Nautical Mile

ABBREVIATIONS AND ACRONYMS
(Continued)

RMI	-	Radio Magnetic Indicator
RNAV	-	Area Navigation
RTCA	-	Radio Technical Commission for Aeronautics
RWY	-	Runway
SAC	-	Strategic Air Command
SC-133	-	Special Committee - 133
SRCH 1	-	"Search 1" Bendix Radar over water search mode
SRCH 2	-	"Search 2" Bendix Radar ground mapping mode
SRCH 3	-	"Search 3" " " " " "
STC	-	Sensitivity Time Constant
TATD	-	Total Along Track Distance
TERPS	-	Terminal Instrument Procedures
TSCT	-	Total System Cross Track Error
UHF	-	Ultra High Frequency Radio Communications
VHF	-	Very High Frequency Radio Communications
VOR	-	Very High Frequency Omnidirectional Range
WXA	-	Weather Alert Mode
WX	-	Weather Mode
$\overline{X}$	-	Mean Value
r	-	Range
σ	-	Sigma (standard deviation)
θ	-	Theta (bearing)

1.0 EXECUTIVE SUMMARY

An overview of the analysis of the performance of airborne radar as an approach aid is presented in this executive summary. In order to attain the proper perspective and to understand the impact of these results it is necessary to briefly review the experiment design, the equipment used and the test objectives. This section begins with a review of these important results and then summarizes the overall method of approach used to answer operational, functional and accuracy questions.

1.1 BRIEF DESCRIPTION OF TESTS PERFORMED AND EQUIPMENT UTILIZED

The Airborne Radar Approach (ARA) System Flight Test Experiment was initiated by the Systems Research and Development Service of the Federal Aviation Administration (FAA). The flight tests were performed by the Approach and Landing Branch of the FAA's National Aviation Facilities Experimental Center (NAFEC). The tests were supported by Systems Control, Inc. (Vt) in the areas of test planning, data collection/reduction and final report preparation.

The ARA tests were performed utilizing the Bendix RDR-1400A airborne radar system. The test vehicle was a CH53A helicopter manufactured by Sikorsky Aircraft and currently based at NAFEC. Four test pilots were provided by NAFEC as subjects for this experiment. The ARA test flights were performed in the general area of NAFEC. Test airspace environments included airport, remote sites and offshore areas. Flight tests for ARA accuracy and procedures development were performed in both skin paint and single beacon radar operating modes. The testing period was from July 1978 to December 1978.

1.2 SUMMARY OF TEST OBJECTIVES

The ARA flight test experiment was designed to obtain both quantitative and qualitative data in the areas of system accuracy, ARA procedures, ARA functional requirements and ATC operational integration problems.

Specific program objectives can be summarized as follows:

1) To assist the FAA and the user community in developing and certifying standard ARA procedures, associated weather minimums and obstacle clearance requirements.

2) To define and quantify specific ARA system functions and characteristics for use in a Minimum Operational Performance Standards document.

1.3 METHOD OF APPROACH

The basic ARA test program consisted solely of approach testing in three major test configurations. These were defined as Reflector Tests,

Skin Paint Tests and Single Beacon Tests. Twenty-four flights were flown in the Airborne Radar Approach experiment. Of these twenty-four flights, six were performed in the skin paint mode using large* and small* passive corner reflectors, three flights were performed in the skin paint mode using oil rigs, a lighthouse and a buoy as targets, and the remaining fifteen flights were allotted to single beacon testing.

Only a single large reflector was utilized during the reflector testing. A sufficient number of small reflectors were obtained to allow testing both individually as well as in multiple configurations using various triple and quadruple patterns. Only qualitative data was taken during the reflector and skin paint testing. This was due to the fact that no radar tracking was available and that these tests were performed early in the ARA program while learning curve effects were still present from both radar interpretation and flight procedures viewpoints. The Single Beacon Tests were performed in three airspace environments. These tests included airport, remote site and offshore testing. The quantitative statistical analysis contained in this report was obtained solely from this single beacon testing.

Four subject pilots were used for the Airborne Radar Approach flight test program. All four pilots alternated as pilot and copilot during the entire test program. All of the subject pilots had operationally used airborne weather radar systems, but none had ever flown an approach to landing using airborne radar. In all cases the proficiency in using the airborne radar came about through actual operational use. There was no attempt to determine a learning curve for the subject pilots using the airborne radar as an approach aid to landing prior to the actual flight test.

There were two pilots per crew with the copilot being the only crew member hooded. For safety reasons, the pilot was not hooded, but instructed to fly only those course headings indicated by the copilot. It was also the pilot's responsibility to handle all communications.

Three separate testing sites were used for the ARA experiment. These were: airport testing conducted in the NAFEC terminal area, remote site testing performed at Bayside, New Jersey, and offshore testing in Delaware Bay using Brandywine Lighthouse and the Five Fathom Buoy as targets. In addition, three different types of approaches were conducted at each site providing a reasonably wide data base. Pilot procedures and profiles were generated in advance in order to insure a well disciplined test environment.

---

*The small and large reflectors had theoretical radar cross-sectional areas of 715 m^2 and 36,153 m^2, respectively.

Figure 1.1 summarizes the overall ARA flight test program. This figure shows that a total of sixty-four approaches were flown: 21 in the reflector mode, 8 in the skin paint mode and 35 in the single beacon mode. Figure 1.1 provides the detailed breakdown of the number and type of approaches flown in each specific mode of operation. In addition, Figure 1.1 shows the experiment balance between interexperiment variables for each mode (e.g. the balance between small and large reflectors). The final point of interest illustrated in Figure 1.1 is the number of each type of approach flown in the airport, remote and offshore areas. As shown in the figure, three ARA approach procedures were used in each of the three test areas. These were direct straight, overhead straight, and overhead offset. The direct straight was used when the winds were favorable for landing upwind in the intended direction and obstruction clearances permitted descent to minimums. The overhead straight was used when the winds favored a downwind direction when approaching the landing site. If neither of these procedures were acceptable, the overhead offset procedure was used to permit the pilot to select a desirable final approach course based on current wind conditions at the landing site. The procedures used for flying all three profiles were identical, with one exception. On the overhead approaches it was necessary for the copilot to call out when directly overhead the target so that the pilot could start an outbound timing of three (3) minutes. At the end of three (3) minutes a procedure turn was executed and the Intermediate Approach Course was acquired. If the overhead offset profile was used it was also necessary to determine, prior to reaching the target, an outbound heading to fly so that upon execution of the procedure turn the pilot was established directly upwind of the target. The accuracy with which each of these approach procedures was executed was determined in detail. These results are presented and discussed in depth in Section 5.3 for each of the three test areas: airport, remote and offshore.

A more detailed description of specific flight profiles, the equipment used, the test procedures, the subject pilots and the data collection/reduction/analysis procedures is presented in Sections 4.1, 4.2, 4.3, 4.4 and 4.5.

1.4 RESULTS AND CONCLUSIONS

This section presents a generalized summary or overview of the primary results and conclusions which may be found in Sections 5.0, 6.0, 7.0 and 8.0. A detailed analysis and expanded discussion of each of the major test areas indicated in Figure 1.1 is contained in Section 5.0. A comprehensive discussion of pilot/copilot procedural operations using ARA is contained in Section 6.0. Section 7.0 is structured to present the data applicable to specific MOPS questions raised by the Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC-133) on ARA. Finally, Section 8.0 presents a more detailed and expanded discussion of the qualitative conclusions regarding ARA as a non-precision approach technique.

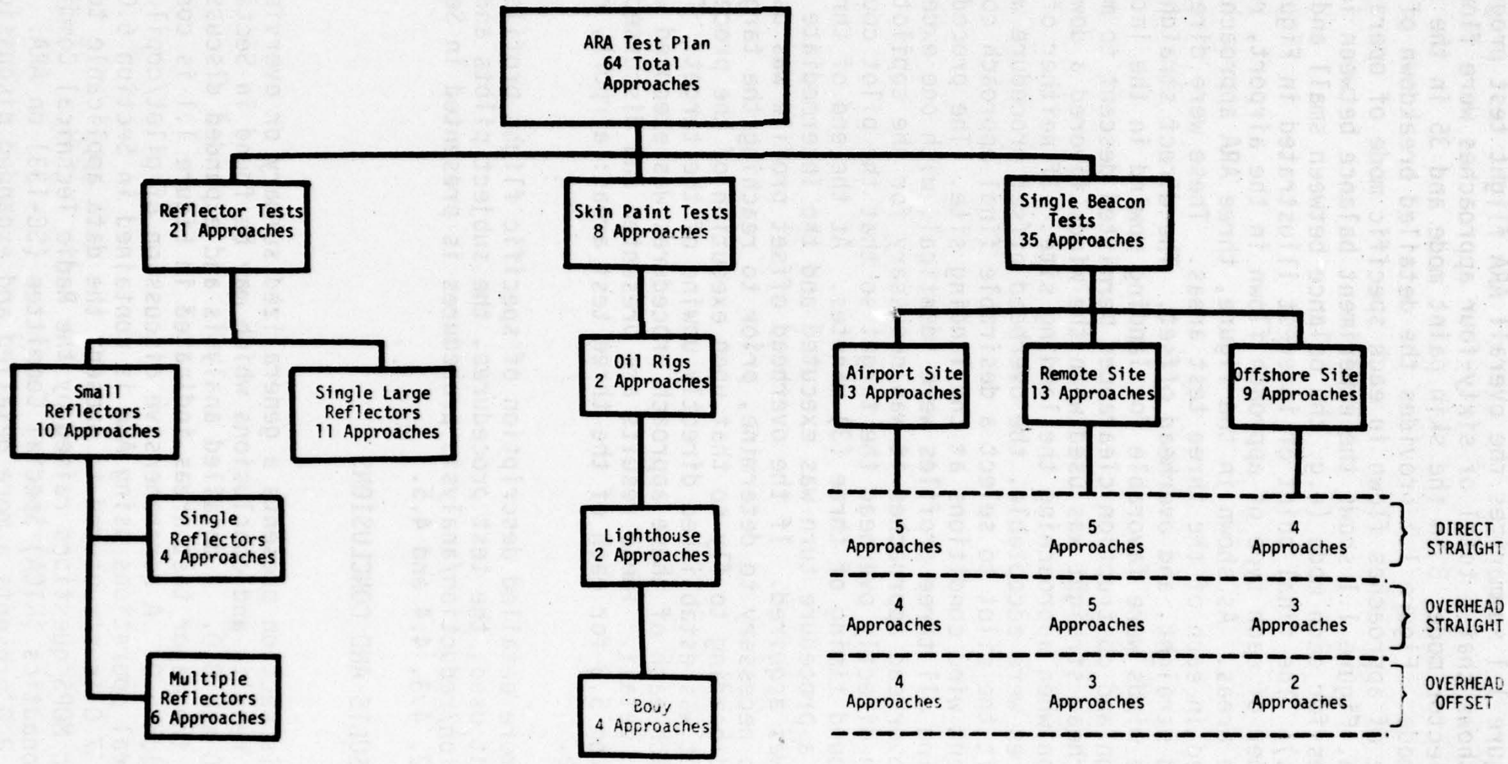


Figure 1.1 Overall ARA Flight Test Program Summary

The summary of results presented herein is subdivided according to the two basic objectives previously stated in Section 1.2. For each of these objectives, a general or qualitative conclusion is stated. Each major conclusion is followed by a summary of the quantitative results which were obtained during the flight test program and are pertinent to that conclusion.

1) The Airborne Radar Approach System tested performed satisfactorily from both an accuracy and an operational viewpoint in the single beacon mode for all three airspace environments.

- The error quantity used to measure this performance was Total System Cross Track (TSCT) error. Summary data for TSCT one-sigma errors over the length of the approach courses for the three test environments were as follows:

TSCT $\pm 1\sigma$	TEST AREA
1.31 nm	Airport
0.82 nm	Remote
0.92 nm	Offshore

- The radar, by design, does not display ground return when operated in the beacon mode. Therefore, there is no ground clutter. However, mutipath returns caused by large structures (steel hanger doors) near the interrogated beacon and returns from other unidentified beacons, increased the display interpretation workload.

- Consistently large displayed target widths were encountered but the widths did not cause any significant operational or procedureal problems. Since target width could not be adjusted as an experimental parameter it is unknown whether or not it does effect the overall accuracy of the approach. A summary of target width data follows:

DISTANCE TO TARGET	TARGET WIDTH Mean	$\pm 1\sigma$
10 nm	13.4°	3.6°
5 nm	12.9°	3.9°
1 nm	15.4°	4.6°

- Although the ARA lateral track keeping accuracy (TSCT) was within specified obstacle clearance airspace limits, ±4 nm established by the RTCA SC-133 MOPS, the Flight Technical Error (FTE) indicated that improvements in pilot procedures used for track acquisition could be made.

- The cross track Airborne System Error (ASE) for ARA was consistently small (less than or equal to ±0.5 nm one-sigma) and showed no dependency on distance from the target. This was true for airport, remote and offshore environments.

- The Along Track Error (ATE) for ARA was consistently the smallest of the four error quantities measured. ATE was generally less than or equal to ±0.25 nm one-sigma.

2) ARA performance <u>in the skin paint mode</u> was not quantified during this experiment. However, qualitatively two significant problems were encountered.

   - Distinguishing landside targets was quite difficult and could cause operational problems.

   - Offshore targets such as oil rigs provide bright returns but are not distinguishable from boats, lighthouses and buoys.

3) ARA performance <u>in the reflector mode</u> was not quantified during this experiment. However, qualitatively it was concluded that very large reflector cross sections are required to provide positive target identification. The small multiple reflector targets in various geometric patterns would not paint any returns on the radar screen. It is unclear if the geometric patterns would or would not provide useful track orientation information.

4) A total of seven ARA system functions and characteristics were investigated to satisfy the requirements of RTCA's SC-133. These were in the areas of technical performance and operational performance. A terse commentary for each of the seven is provided in the following list. For a more detailed discussion refer to Section 7.0.

<u>TECHNICAL PERFORMANCE</u>

A. RANGE PERFORMANCE

(1) Single Beacon - 21 nm at 1000 feet altitude and the beacon at ground level

- 30 nm at 1000 feet altitude and the beacon at 30 feet above water level.

(2) Reflectors - 5 nm for large reflectors

- Small reflectors were indistinguishable from ground clutter.

B. BEARING ACCURACY

	Mean	$\pm 1\sigma$
5 nm From the Beacon	- 1.2°	±3.3°
10 nm From the Beacon	- 1.5°	±2.2°

C. DISPLAY READABILITY - Not a specific test variable. Qualitative observations indicated that the readability was adequate except in direct sunlight.

D. DISPLAY RESOLUTION - Not a specific test variable. Observations and calculations showed the radar display tested had adequate resolution. In addition, the displayed size of the beacon return did not affect the pilot's ability to conduct the approach.

OPERATIONAL PERFORMANCE

A. GROUND CLUTTER IN THE MAPPING MODE

(1) Skin Paint testing offshore showed it was often difficult to distinguish the desired target from ships, lighthouses or buoys.

(2) Small reflectors could not be distinguished from the ground clutter.

(3) Large reflectors were only distinguishable from the ground clutter within 5 nm of the target.

B. REFLECTOR DISCRIMINATION - Since the small reflectors would not paint any returns it is unknown whether or not the multiple patterns offered an improvement in lateral guidance.

C. PERFORMANCE IN THE BEACON MODE - Accuracy, functional and operational performance was acceptable. Obstacle clearance airspace limits were achievable, as tested, at airport, remote and offshore test sites. However, workload was high due to the constant monitoring of the gain, tilt and range controls required to maintain the desired aircraft heading. Display enhancements to improve data interpretation would be desirable, especially a faster update rate. The slow update rate introduces system errors in the along track and cross track direction.

2.0 INTRODUCTION

This report was prepared to summarize the results of the Airborne Radar Approach (ARA) flight tests. These tests were performed by Approach and Landing Branch (ANA 110) of the Federal Aviation Administration's National Aviation Facilities Experimental Center (NAFEC). The tests were supported by Systems Control, Inc. (Vt) [SCI (Vt)] in the areas of test planning, data collection/reduction and final report preparation. The test vehicle was a CH53A helicopter manufactured by Sikorsky Aircraft. Flight tests for ARA accuracy and procedures development were performed in three distinct operational environments. These were the airport environment, the remote site (landside) environment and the offshore environment. The test areas were all located near NAFEC. In particular, the airport ARA tests were performed at NAFEC, the remote tests were performed within a sixty nautical mile radius of NAFEC, and the offshore tests were conducted in Delaware Bay. The testing period was from July 1978 to December 1978. The primary reasons for the ARA flight test program were: 1) to evaluate the ARA concept both quantitatively and qualitatively in the areas of accuracy and flight procedures; 2) to provide empirical inputs for the "Minimum Operational Performance Standard" being generated by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 133 (SC-133).

2.1 BACKGROUND

Continued expansion in the application of helicopters to the accomplishment of civilian oriented tasks depends to a significant extent on the capabilities of the aircraft and the navigation systems in order to operate in all weather conditions. Much of the future growth of the helicopter market will be in applications that involve the transport of people in such areas as offshore oil support, in corporate transport, and eventually in scheduled transportation. The effectiveness of the helicopter in these missions depends on its ability to circumvent the time delays of other modes of transportation. If weather results in a significant number of cancellations and delays, the helicopter's effectiveness is lost. A particularly interesting facet of this general problem area arises from the needs of helicpoter operators to fly in adverse weather in remote areas. This type of mission generates a requirement for a self-contained helicopter instrument approach system for landing on oil rigs and other landing areas remote from conventional navigational aids. Such a system would also benefit the corporate operator who desires instrument approach minimums equivalent to conventional non-precision approach procedures at a variety of sites, many of which may be of an ad hoc nature, but who would be unable to afford the time and expense necessary to achieve the installation of ground navigation aids.

Weather radar used in the mapping mode for IFR approaches offers a possible immediate low-cost solution. The application of airborne weather/mapping radar as an approach and landing aid has generally become known throughout the industry as an Airborne Radar Approach (ARA) System. This terminology will be used frequently in this document.

The major impetus for the ARA operational application has come from the Helicopter Association of America (HAA) in general, and its offshore energy exploration support members in particular. In addition to the basic requirements of the HAA to stimulate the development of helicopter IFR procedures and systems, particularly at sites where instrument approach procedures are unavailable, the necessity to provide approach capability to offshore oil rigs under Instrument Meteorological Conditions (IMC) is critical to their mission. The HAA, therefore, has consistently requested the FAA to develop standard operational procedures and equipment certification criteria as regards ARA systems and their operation in the IFR portion of the National Airspace System as one means of providing this instrument approach and landing capability. Certain offshore helicopter operators have been granted approval for ARA approaches on a singular basis, but no general certification criteria currently exists within the FAA.

In recognition of the emerging need for some measure of equipment performance criteria, early in 1977 the Radio Technical Commission for Aeronautics (RTCA) constituted a Special Committee (SC-133) for the purpose of developing a Minimum Operational Performance Standards (MOPS) for ARA systems for helicopters. This MOPS document will contain both operational and technical performance criteria which might ultimately be used for FAA certification purposes. At least two requests have been made of the FAA by RTCA, in behalf of SC-133, which contains a postulated operational scenario and initial technical performance specifications. However, no substantive technical data was previously available on many of the critical issues concerning the ARA system application.

2.2 ARA TEST CONCEPTS

All test programs are necessarily constrained by the practical considerations of time and money. In the case of the ARA testing there were additional considerations which further limited the investigation. It is therefore necessary to identify in some detail what this ARA evaluation does and does not cover.

Most of the following discussion concerning the ARA flight test limitations emanate from considerations of the aircraft used as the test vehicle. The Sikorsky CH53A has sufficient passenger and payload capacity for experimental test purposes, however, due to limited fuel capacity, it has an effective flight endurance of approximately 1 3/4 hours. For this reason it was decided to limit the offshore portion of this evaluation to those water-based targets located within the useable operating radius of the aircraft rather than attempt to fly approaches to the existing oil rigs located 60 miles east of Atlantic City. Section 4.0 identifies the specifics of the test design, however, it should be noted that approximately 1/3 of the 30 hour flight test program (or approximately 11 hours) were assigned to offshore testing. The remainder of the testing has been assigned to various elements of landside testing.

In order to investigate a spectrum of target signatures it was decided to investigate radar performance against: a) beacon targets over both land and water, b) skin paint or primary return targets (over water), and c) corner reflector augmented targets, also as a primary return. RTCA SC-133, in particular, has requested data concerning all three target modes.

Two other issues relating to the scope of the current effort should be discussed. First, there were two airborne radar systems available for test, the RCA Primus 50 and the Bendix RDR-1400A. Both systems have both primary ground mapping and beacon modes. In addition, the RCA unit has a combined beacon/ground mapping mode (which was included as a requirement in the draft ARA MOPS generated by RTCA SC-133). Under the previously discussed limitation of 30 flight hours, it was not practical to equally test both radar systems, since the reduced number of data samples from each radar might lose their statistical significance. The ARA evaluation was therefore configured using only one system for the specified tests. The Bendix RDR-1400A was used for all the initial testing. Supplemental testing with the Primus 50 operating both in the combined beacon/ground mapping mode will be performed subsequently.

The second issue relates to the subject of the pilot population sample used for these tests. Since radar display interpretation and pilot steering techniques form a major portion of this investigation, it was considered critical that a limited number of pilots-in-command be utilized for these experiments. Although a wide variety of subject pilots is usually a goal in the design of such flight experiments, due to the small number of flight hours available for these initial tests, the number of pilots used was limited to four. The subject of pilot performance variability should properly be studied in a more comprehensive and dedicated experiment.

2.3 PURPOSE OF THE TESTS

Simply stated, the purpose of this ARA test program was twofold. First, to acquire a statistically significant data base concerning operational procedures and overall ARA system performance that will assist the FAA and the airspace users alike in developing and certifying standard approach procedures and associated weather minimums through the application or modification of TERPS criteria. Second, to quantify specific ARA system performance parameters for use by RTCA SC-133 and the FAA in specifying ARA required technical performance. Each of these major objectives is expanded and discussed in depth in Section 3.0.

2.4 ORGANIZATION OF THE REPORT

The results of the ARA flight test program are presented in the remainder of this report. Section 4.0 provides a detailed equipment summary, a flight test description, a review of test profile designs, data acquisition procedures and data reduciton/analysis techniques.

Sections 5.0 presents and documents the specific results obtained in five major areas:

1) Airborne Radar as an Approach Aid
2) Development of Pilot Procedures
3) Detailed Accuracy Data
4) Operational Evaluation of the ARA Concept
5) Specific ARA Results in Various Operational Modes

Section 6.0 extracts the pilot/copilot operational data and discusses ARA from crew workload, blunders and training concepts viewpoints. Section 7.0 provides the specific flight test data pertinent to the technical and operational performance questions raised by RTCA's SC-133. Section 8.0 presents major qualitative conclusions as they relate to the stated program objectives from Section 3.0. Finally, Section 9.0 specifies recommended ARA improvements necessary for better track orientation during the critical approach phase of flight.

3.0 DETAILED TECHNICAL OBJECTIVES

The general objectives of this initial investigation of the ARA concept were to evaluate and/or establish basic ARA operating procedures and overall system performance as well as to quantitiatively define specific ARA system performance parameters. The results of this program are therefore applicable to the FAA, RTCA and the user community (HAA). For purposes of discussion these test objectives have been grouped into two categories, namely Technical and Operational. Subsequent to this discussion, a correlation will be presented between the stated test objectives and the specific test results obtained (Section 5.0)

A. Technical Performance Objectives

1) Range Performance -- To establish the maximum and minimum radar ranges at which beacon, reflector, and skin paint targets, respectively, can be acquired, identified and tracked. SC-133 has specified a maximum range requirement of at least 25 nm in clear weather and 15 nm with 4 mm/hr/nm of intervening precipitation. Minimum range is specified at 1000 ft.

2) Bearing Accuracy -- To determine, for the system tested, the accuracy in bearing with which a target can be displayed. SC-133 requires ±3°.

3) Display Readability -- To validate the specified display readability. SC-133 currently requires that the display be functionally readable when viewed under conditions of 2000 foot lamberts impinging upon the display face.

4) Impact of Antenna Stabilization -- To validate the requirement of SC-133 for antenna stabilization up to a vector sum of ±30° for combined roll, pitch and yaw and to evaluate the impact of values in excess of ±30° on display discrimination.

5) Impact of Precipitation on System Performance -- To collect precipation data in conjunction with item A,1) above. Although weather conditions are not an explicit test variable, any data on radar system performance under precipitation conditions would be most beneficial and desirable.

6) Display Resolution -- To assess display resolution requirements. Although this parameter is an inherent system design characteristic, it is considered desirable to obtain data on subjectively viewed display resolution for comparison with the requirements of SC-133.

B. Operational Performance Objectives

1) Basic Beacon vs. Reflector Performance Comparison -- To evaluate the relative ability of the radar/operator to acquire and effectively utilize beacon return data compared to returns from corner reflectors when the radar is operated in the ground mapping mode (both offshore and onshore).

2) Beacon/Ground Clutter Discrimination -- To evaluate the operational viability of the combined beacon/ground mapping mode of operation as currently required by SC-133 as an adjunct to B, 1) above.

3) Beacon/Reflector Proximity -- To evaluate the limiting (minimum) distance in both azimuth and range between multiple targets such that individual targets can be acquired and identified for both beacons and reflectors.

4) Lateral Cross Track Error and Flight Technical Error -- To establish statistically significant values for lateral cross track error for the overall ARA system and lateral flight technical error for the pilot/operator under actual operational approach conditions for each of the basic modes of operation (beacon, reflector, skin paint). These values quantify the ability of the pilot to utilize the ARA system to maintain a desired lateral ground track.

5) Longitudinal Along Track Error and Letdown Error -- To establish statistically significant values of longitudinal along track error for the overall ARA system and the along track flight technical error (Letdown Error) for the pilot/operator. These values quantify the ability of the pilot to utilize the ARA system to define and identify a step-down fix and/or a missed approach point in order to execute a non-precision approach vertical profile.

6) Offshore Target Discrimination -- To evaluate the ability of the ARA system to acquire and identify offshore targets in the variety of back scatter conditions as influenced by sea state and water depth parameters. While not an explicit test variable, careful note should be made of such conditions during each test in order to establish any possible correlation.

7) Pilot/Operator Procedures, Workload and Blunder Performance -- To establish quantitative measures, wherever possible, of pilot performance factors such as operational procedures, comparative workload and blunders as related to the different ARA operating modes (beacon, reflector, skin paint). In addition, it will be necessary to obtain baseline data for normal instrument approach procedures for comparison purposes.

Section 4.0 which follows, describes the ARA test plan which was configured to meet these stated objectives. Following Section 4.0, a correlation between test objectives and specific flight test results is presented.

4.0 DESCRIPTION OF THE ARA EXPERIMENT DESIGN

This section describes the equipment, test profiles, procedures, subject pilots and data requirements necessary for the Airborne Radar Approach flight test program. The experiment was designed to test an airborne weather/ground mapping radar as an approach aid to landing using two different modes: skin paint and transponder beacon. In the skin paint mode corner reflectors and other prominent objects such as lighthouses, oil rigs and buoys were used as targets. Three distinct environments were also included in the testing to determine the capability of the airborne radar to aid the pilot in making a safe approach where other navigational aids are not available. These were as follows: airport, remote site and offshore site. In addition to testing three different terrain environments, three different approach profiles were tested at each site to determine the suitability of each procedure.

4.1 EQUIPMENT SUMMARY

This section describes the equipment used in the Airborne Radar Approach flight test program at NAFEC in Atlantic City, N.J.

4.1.1 The Bendix RDR-1400A Radar

The Bendix RDR-1400A Radar system tested was a multi-mode, 10 KW X-band airborne radar. The system provides up to three air-to-surface search and detection modes plus the usual weather avoidance mode. It also contains an additional capability of a transponder beacon mode. The search modes provide both a ground mapping function along with the ability to detect and display prominent surface objects. The beacon mode is a special function used to interrogate and receive pulses from a ground based transponder(s) within line-of-sight range. The bearing and distance of the target is then displayed on the CRT (cathode ray tube) free of any ground clutter.

The RDR-1400A uses digital techniques to continuously display a reliable return from significant weather or terrain. The display features an alphanumeric read-out directly on the screen depending on the selected mode, range, and range intervals. System checkout, either in the air or on the ground, is a straightforward procedure.

The entire RDR-1400A radar system consists of 3 separate units: receiver-transmitter, display indicator, and antenna. The antenna used was a gyro stabilized twelve inch slotted flat plate antenna mounted in a radome directly on the nose of the aircraft. The display indicator was mounted in the center of the aircraft's flight instrument panel. This central location gave both the pilot and copilot easy accessibility to the display indicator and its associated controls. All operator controls and indicators are located on the RDR-1400A front panel as shown in Figure 4.1.

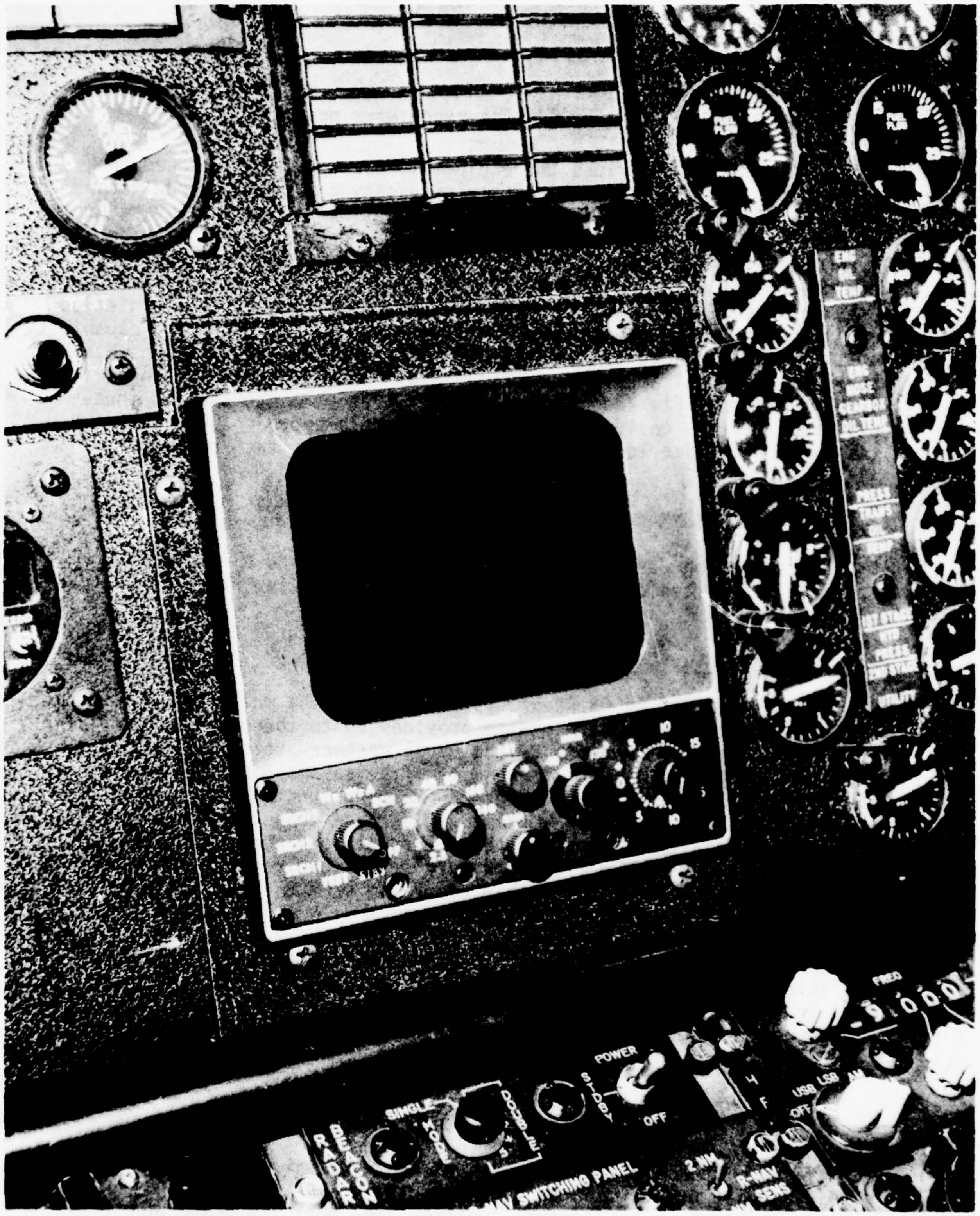


Figure 4.1 Bendix RDR-1400A Front Panel

The mode selector switch located on the display unit offers six distinct display capabilities.

a) SRCH 1 - Mode normally used for over water search. This mode optimizes point targets within a sea clutter background. It is generally used for mapping ground targets or surface craft at short range. This mode optimizes short range resolution and clutter rejection.

b) SRCH 2 - Principal use for this mode is high resolution at all ranges. SRCH 2 offers no clutter rejection so it is generally used for ground mapping only. This mode offers precision ground mapping over many types of terrain.

c) SRCH 3 - Mode normally used for the mapping of oil slicks. SRCH 3 offers long range mapping and/or maximum clutter returns.

d) WX - Weather mode: in this mode the receiver is optimized for weather detection. It provides early warning of bad weather and possible storm activity enroute.

e) WXA - This mode is the same as WX with one exception. When operating in the WXA mode the display flashes contoured areas to alert the pilot of clouds with high rainfall rates.

f) BCN - This mode has the capability to interrogate beacon transponders which receive a frequency of 9375 MHz and transmit back at 9310 MHz. The BCN mode allows the pilot to navigate to a predetermined target or landing site, while continuously displaying both range and bearing to the target. This mode eliminates any background clutter and displays only the beacon or beacons within the field of view. Depending on aircraft position and altitude, the beacon target(s) can be received at considerable distances.

The RDR-1400A also offers an indicator test pattern. When the mode selector switch is in the TEST position the pilot then has the ability to determine if the radar is operating, either in the air or on the ground. The range selector switch offers range selection from

240 nautical miles to as close as 2.5 nautical miles, full scale, with range marks varying according to different scales selected. The tilt control adjusts the tilt of the antenna in relation to the longitudinal axis of the aircraft to allow best indicator presentation. Range of tilt control adjustment is ±15 degrees. The receiver gain is adjustable for the search and beacon modes only.

In the other operating modes the gain is preset, therefore the gain control has no effect. The Scan/Stab selector switch offers the opportunity to select one of two antenna scan angles. The 120° STAB position places the antenna in a 120° scan mode, ±60° each side of the aircraft longitudinal axis. The 40° STAB position places the antenna in a 40° scan mode, ±20° each side of the aircraft longitudinal axis.

4.1.2 The Transponder Beacons

The transponder beacons used during the Airborne Radar Approach testing were manufactured by the Motorola Co., Model SST-181 X-E. The transponder beacons operate at a receive frequency of 9375 MHz and a transmit frequency of 9310 MHz. They have a power output of 400 watts. The transponder beacons were powered by a series of twelve volt lead-acid batteries mounted on a small cart. Figure 4.2 shows the transponder beacon mounted in a portable, water-tight case.

4.1.3 Corner Reflectors

The corner reflectors used in the skin paint flight tests were of two sizes: A 36" major edge (25.5" corner edge) and a 96" major edge (68" corner edge). The smaller reflectors were manufactured by ITT Gilfillan. These reflectors are of a rigid alloy construction and are built to fairly precise tolerances. The large reflector was built at NAFEC's project laboratory of sheet aluminum and angle iron, but it was found that it was not particularly rigid or especially precise. When viewed directly down the axis of symmetry the reflectors presented a theoretical maximum radar cross section of 715 m^2 and 36,153 m^2, respectively.

4.1.4 Flight Test Helicopter

The aircraft utilized for the Airborne Radar Approach (ARA) flight test program was a NASA Sikorsky CH53A helicopter (N-39) as shown in Figure 4.3. This type of aircraft normally cruises at 140 kts. and is primarily used by NAFEC and NASA for flight test purposes. The test aircraft was based out of NAFEC in Atlantic City, N.J.

The CH53A helicopter is a fully operational IFR aircraft. Both the pilot and copilot have full sets of operating flight controls and instruments. The center console houses control heads for single UHF and HF, and DUAL VHF communications systems, along with DUAL Collins NCS-31A RNAV systems. The front panel contained various instruments including a flight director, HSI, RMI, Radar and Barometric altimeters as shown in Figure 4.4

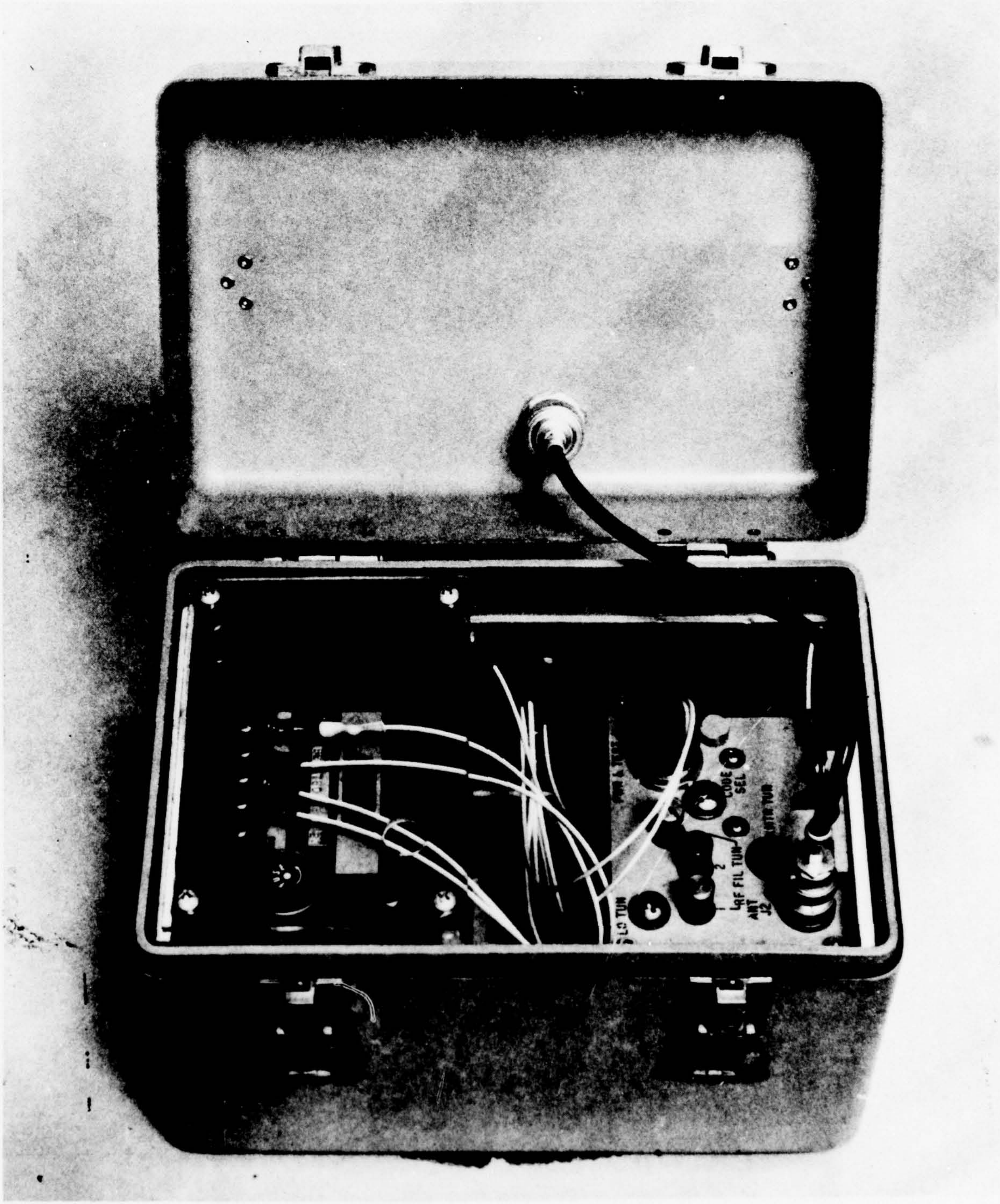


Figure 4.2 The Transponder Beacon

Figure 4.3 NASA Sikorsky CH53A Test Helicopter

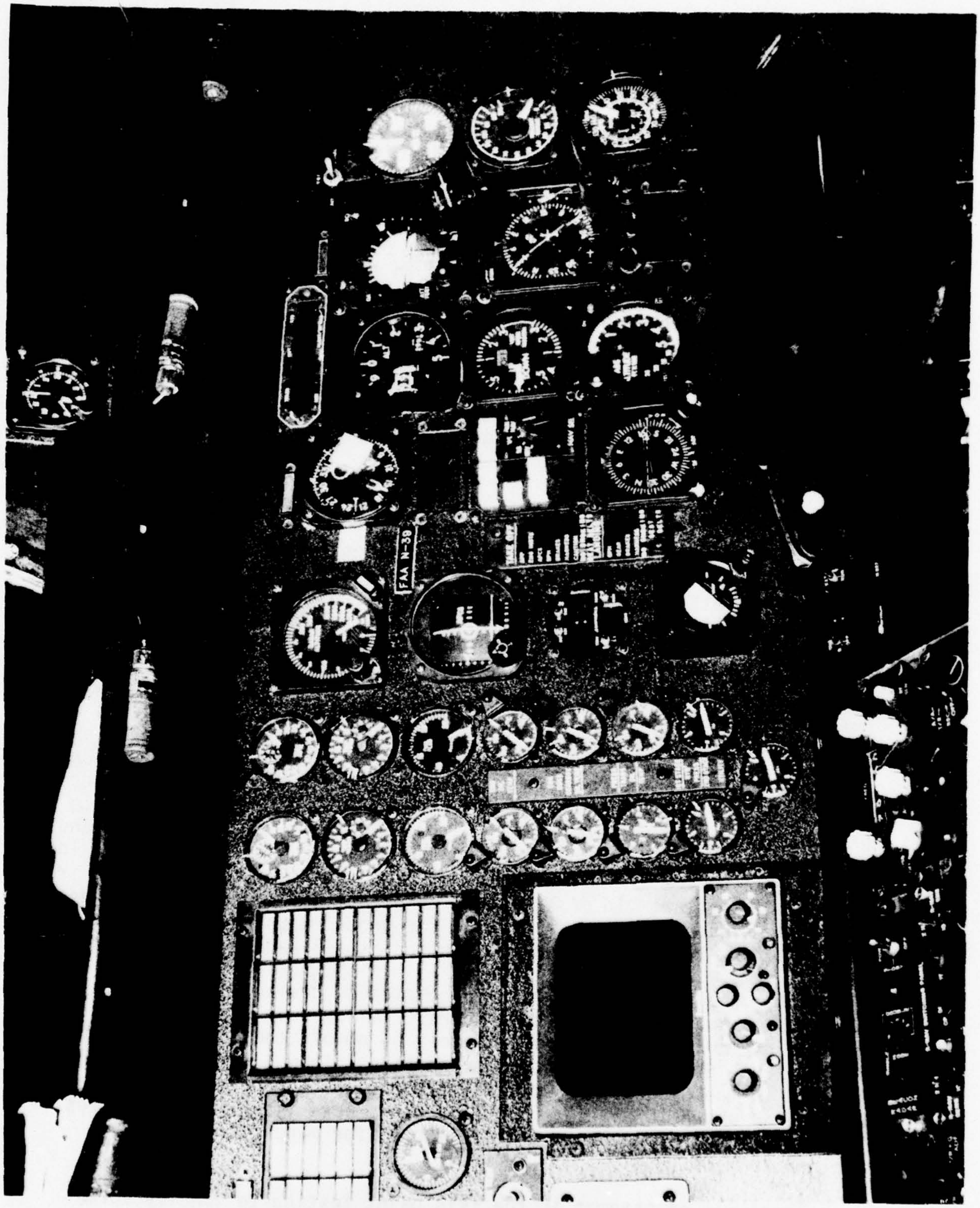


Figure 4.4 Flight Test Helicopter (CH53A) Front Instrument Panel

4.2 TEST PROFILES AND PROCEDURES

Twenty-four flights were flown in the Airborne Radar Approach (ARA) flight test program at NAFEC in Atlantic City, N.J. Of these twenty-four flights, six were performed in the skin paint mode using large and small corner reflectors during the testing period from 7 July 1978 to 4 August 1978. Table 4.1 presents the reflector flight test matrix, showing type of reflector used and number of approaches at each location. Three additional flights were conducted in the skin paint mode using oil rigs, a lighthouse, and a buoy as targets during the latter part of August 1978. Table 4.2 presents the resulting skin paint flight test matrix. The remaining fifteen flights were dedicated to Airborne Radar Approach single beacon testing, conducted at three distinct sites: airport, remote, and offshore. These were conducted during a testing period from 22 October 1978 to 14 December 1978. Table 4.3 presents a summary of the ARA single beacon approach flight test matrix.

4.2.1 Skin Paint Mode

The effort in this portion of the testing was concentrated on using both passive reflectors and prominent surface objects such as lighthouses, oil rigs and buoys as targets. Additional limited testing was performed to offshore targets. The passive reflectors, as discussed in section 4.1.3, were of two sizes. The six flights flown using the reflectors were conducted using NAFEC's runways 4 and 17, and also a remote site located at Bayside, N.J. on the Delaware Bay. Small reflectors were used singularly and in varying patterns while large reflectors were used singularly. For example, the small reflectors were set up in a triangular pattern at the end of the runway so that track orientation and site identification could be achieved. Four small reflectors were also lined up on the centerline of runway 17 with the intent being to provide better track orientation and identification. Single small and large reflectors were set up at both the remote and airport sites. The purpose was to see if reflectors of varying size could be discerned from the ground clutter. In most of the reflector testing the SRCH 2 mode was used, since it is generally used for ground mapping only, along with the fact that it has high resolution at all ranges.

After the reflector tests were completed, the skin paint tests using oil rigs, Brandywine Lighthouse and Five Fathom Buoy were initiated. The oil rigs were located approximately 60 nm off the coast of southern New Jersey. Brandywine Lighthouse and Five Fathom Buoy were both located in the Delaware Bay off the western and southern coast of New Jersey, as shown in Figure 4.5. Approaches were flown to these sites in SRCH 1 mode, since it is primarily used for mapping objects in a sea environment.

There was no attempt in the skin paint testing to specify formal approach profiles or procedures. The tests were strictly experimental in nature. It was planned that only qualitative data be collected, and also to expose both the flight crews and test personnel to the

Table 4.1 Reflector Flight Test Matrix

Flight	Airport Site		Remote Site	Reflector Type And Configuration	Number of Approaches
	Rwy 4	Rwy 17			
1	X			Single-Small	2
2		X		Triple-Small Triangular Pattern	2
			X	Single-Small	2
3		X		Triple-Small Triangular Pattern	2
		X		Quadruple-Small Centerline Pattern	2
4		X		Single-Large	2
5		X		Single-Large	2
6		X		Single-Large	3
			X	Single-Large	4
				Total	21

Table 4.2 Skin Paint Flight Test Matrix

Flight	Offshore Site			Configuration	Number of Approaches
	Oil Rigs	Brandywine Lighthouse	Five Fathom Buoy		
1	X			Skin Paint	2
2		X		Skin Paint	2
3			X	Skin Paint	4
				Total	8

Table 4.3 ARA Single Beacon Approach Flight Test Matrix

Location	Airport Site												Remote Site												Offshore Site												Number Of Approaches	Pilot	Copilot	Date Flown
Procedure	Direct Straight				Overhead Straight				Overhead Offset				Direct Straight				Overhead Straight				Overhead Offset				Direct Straight				Overhead Straight				Overhead Offset							
Segment Length NM	25	5	25	5	25	5	25	5	25	5	25	5	25	10	25	10	25	10	25	10	25	10	25	10	25	10	25	10	25	10	25	10	25	10	25	10				
Approach Course TN	Rwy 26		Rwy 04		Rwy 26		Rwy 08		Rwy 26		Rwy 08		264°		330°		264°		330°		264°		330°		150°		222°		150°		222°		150°		222°					
Flight #																																								
1			X X X	X																																	4	C	B	12/12/78, 12/13/78 12/14/78
2					X	X	X	X																													4	D	C	12/13/78
3									X	X	X	X																									4	A	C	11/3/78
4													X	X																			X				3	A	D	11/14/78
5																X			X								X	X									4	D	A	11/15/78
6																			X	X																	2	A	C	11/20/78
7																					X	X		X													3	B	D	11/29/78
8														X				X																			2	C	A	12/1/78
9														X			X								X					X							4	A	B	12/12/78
10		X																									X				X	X		X			5	B	A	12/13/78
Total		1	3	1	1	1	1	1	1	1	1	1	1	3		1	1	1	2	1	1	1		1	1		2	1		1	1	1	1	1			35	A-7 C-5	B-4 D-4	

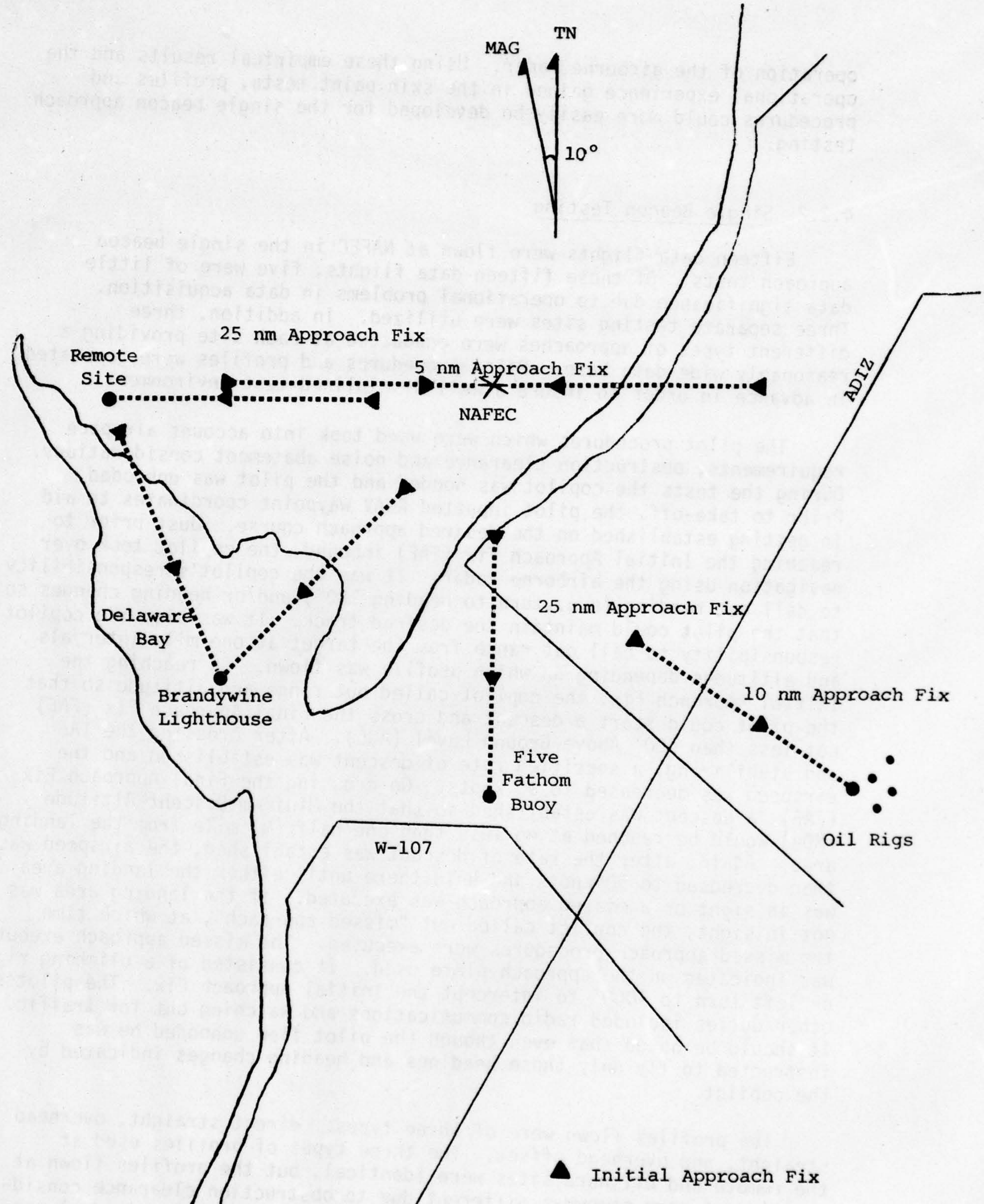


Figure 4.5 Airborne Radar Approach Geometries

operation of the airborne radar. Using these empirical results and the operational experience gained in the skin paint tests, profiles and procedures could more easily be developed for the single beacon approach testing.

4.2.2 Single Beacon Testing

Fifteen data flights were flown at NAFEC in the single beacon approach tests. Of these fifteen data flights, five were of little data significance due to operational problems in data acquisition. Three separate testing sites were utilized. In addition, three different types of approaches were conducted at each site providing a reasonably wide data base. Pilot procedures and profiles were generated in advance in order to insure a well disciplined test environment.

The pilot procedures which were used took into account airspace requirements, obstruction clearance and noise abatement considerations. During the tests the copilot was hooded and the pilot was unhooded. Prior to take-off, the pilot inputted RNAV waypoint coordinates to aid in getting established on the desired approach course. Just prior to reaching the Initial Approach Fix (IAF) inbound, the copilot took over navigation using the airborne radar. It was the copilot's responsibility to call out heading (e.g.,turn to heading 180°) and/or heading changes so that the pilot could maintain the desired track. It was also the copilot's responsibility to call out range from the target at one mile intervals and altitudes depending on which profile was flown. On reaching the Initial Approach Fix, the copilot called out range and altitude so that the pilot could start a descent and cross the Final Approach Fix (FAF) not less than 500' Above Ground Level (AGL). After crossing the IAF and stabilizing, a specified rate of descent was established and the airspeed was decreased to 90 knots. On crossing the Final Approach Fix (FAF), a descent was established so that the Minimum Descent Altitude (MDA) would be reached at no less than one half (½) mile from the landing area. Again, after the rate of descent was established, the airspeed was then decreased to 50 knots and held there until either the landing area was in sight or a missed approach was executed. If the landing area was not in sight, the copilot called out "missed approach", at which time the missed approach procedures were executed. The missed approach executed was indicated on the approach plate used. It consisted of a climbing right or left turn to 1000' to intercept the Initial Approach Fix. The pilot's other duties included radio communications and watching out for traffic. It should be noted that even though the pilot flew unhooded he was instructed to fly only those headings and heading changes indicated by the copilot.

The profiles flown were of three types: direct straight, overhead straight, and overhead offset. The three types of profiles used at the remote and offshore sites were identical, but the profiles flown at the airport were somewhat different due to obstruction clearance considerations. In all cases the Missed Approach Point (MAP) remained at one half (1/2) mile from the beacon and 200 feet, but in the airport area the Initial Approach Fix (IAF) and the Final Approach Fix (FAF) were moved in closer to the Missed Approach Point (MAP). At the airport the IAF was located at 5 nautical miles from the beacon, as opposed to

10 nautical miles at the remote and offshore sites. Also, the FAF at the airport was located at 1.5 nautical miles from the beacon as opposed to 6 nautical miles at the remote and offshore sites using the direct straight profiles. All the altitudes for all profiles remained the same; i.e., 1000' on the Initial Approach Course, 500' on the Intermediate Approach Course and 200' on the Final Approach Course. Figures 4.6 thru 4.11 show the different types of approach profiles flown with their associated plan views.

The three profiles used were chosen with different considerations in mind. The direct straight was used when the winds were favorable for landing upwind in the intended direction and obstruction clearance permitted descent to the minimums stated. If the winds favored a downwind direction at the landing site then the overhead straight profile was utilized to situate the pilot upwind for landing. If neither of the above was acceptable, the overhead offset procedure allowed the pilot to determine his own final approach course based on current wind conditions at the landing site. This final approach course was determined prior to the flight based on current wind conditions. The procedures used for flying all three profiles were identical, with one exception. On the overhead approaches it was necessary for the copilot to call out when directly overhead the target so that the pilot could start an outbound timing of three (3) minutes. At the end of the three (3) minutes, a procedure turn was executed and the Intermediate Approach Course was acquired. If the overhead offset profile was used, it was also necessary to determine, prior to reaching the target, an outbound heading to fly so that upon execution of the procedure turn the pilot was established directly upwind of the target.

4.3 SUBJECT PILOT EXPERIENCE AND TRAINING

Four subject pilots were used for the Airborne Radar Approach flight test program. All four pilots alternated as pilot and copilot during the entire test program. All pilots involved were resident at NAFEC in Atlantic City, N.J.

The training of the subject pilots in the operational use of airborne radar as an approach aid to landing was begun in July, 1978. Two subject pilots were given a two hour briefing on the principles and procedures used during the approach. The pilots themselves were already somewhat familar with the operational use of the airborne radar. All of the subject pilots had previous contact with airborne weather radar systems, but none had ever flown an approach to landing using airborne radar. In all cases the proficiency in using the airborne radar came about through actual operational use. There was no attempt to determine a learning curve for the subject pilots using the airborne radar as an approach aid to landing prior to the actual flight test.

As discussed earlier the four pilots alternated pilot and copilot positions. There were two pilots per crew with the copilot being the only crew member hooded. The pilot was not hooded for safety reasons,

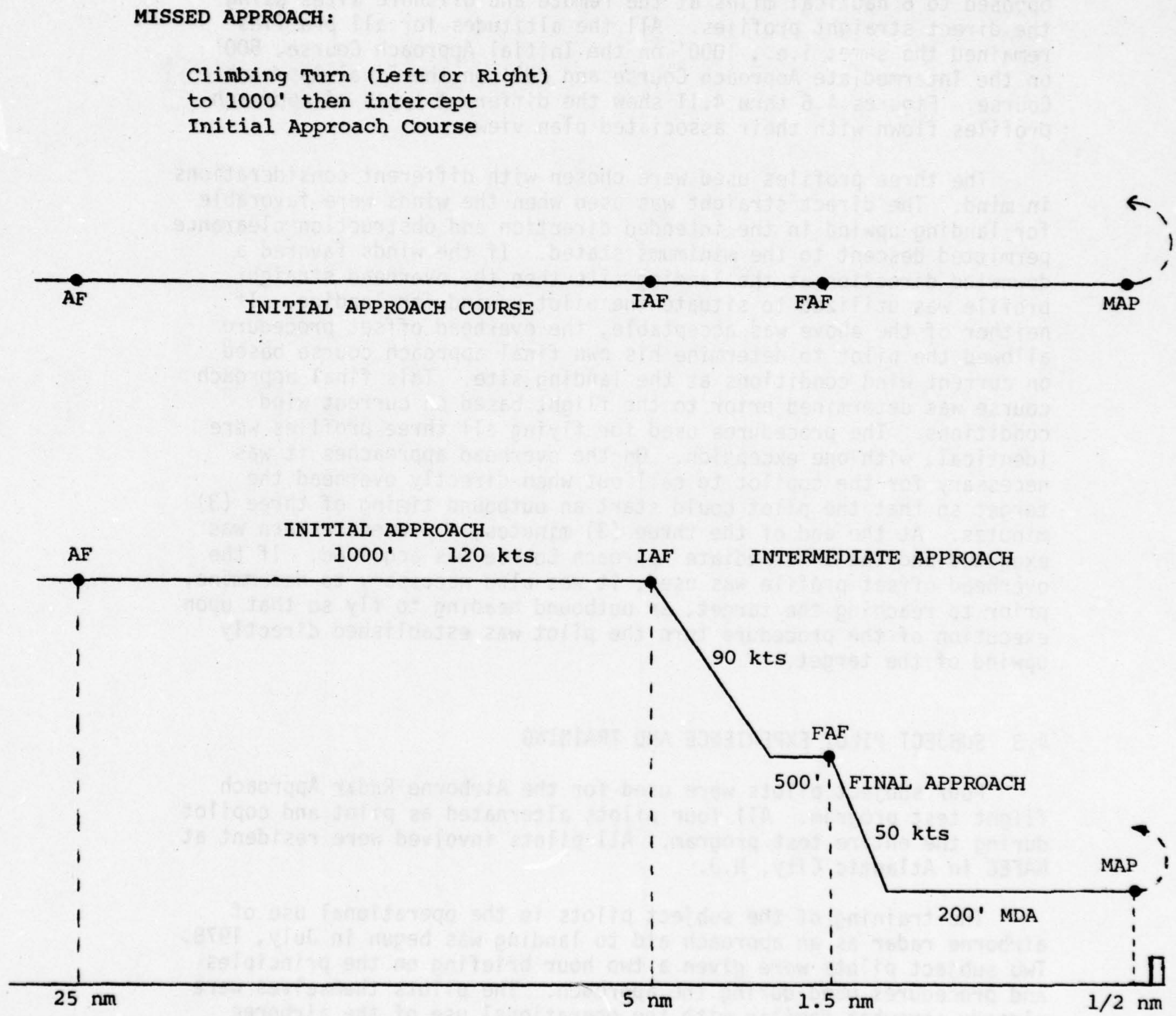


Figure 4.6 Profile 1: Direct Straight Airport Site

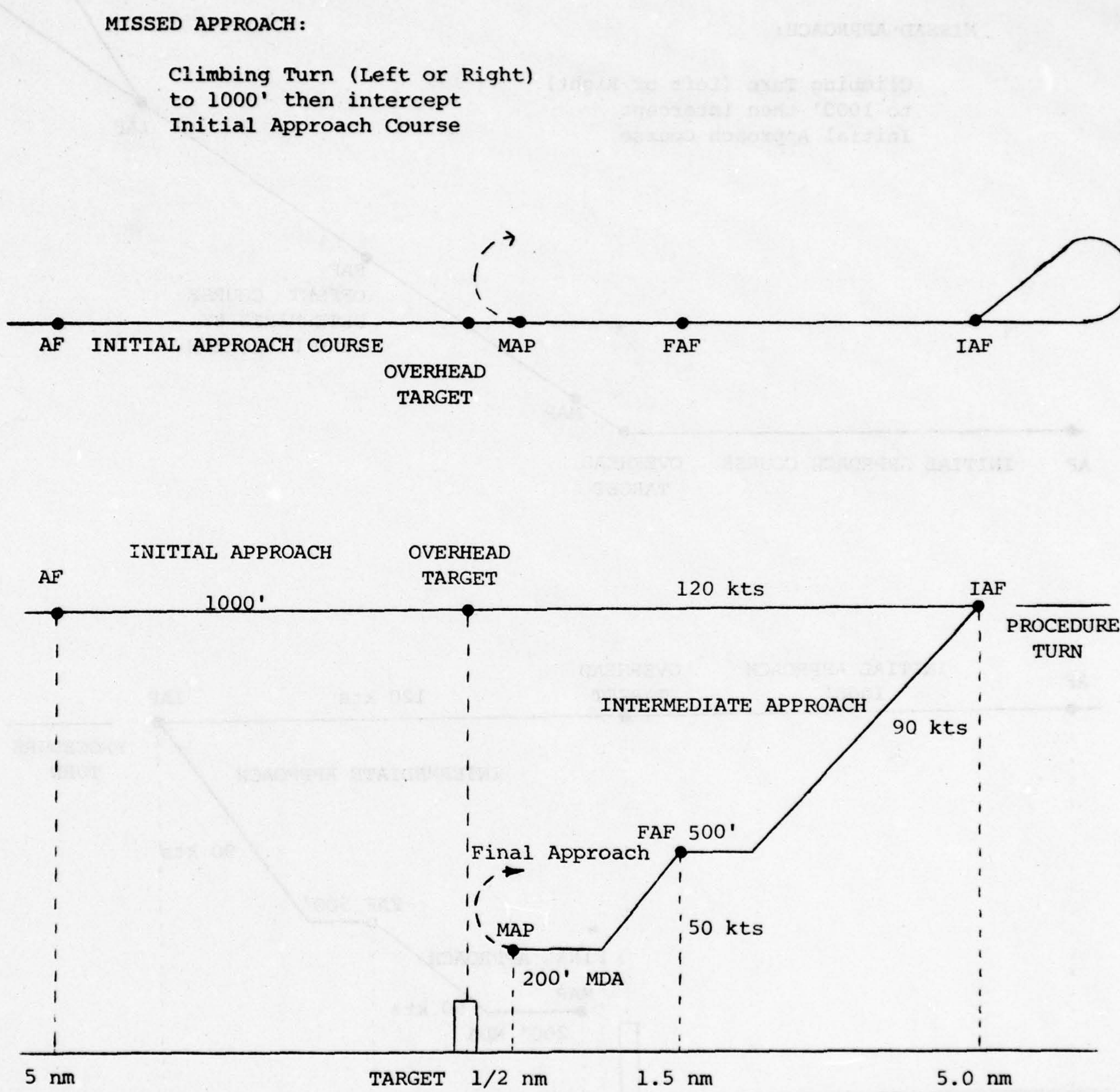


Figure 4.7 Profile 2: Overhead Straight Airport Site

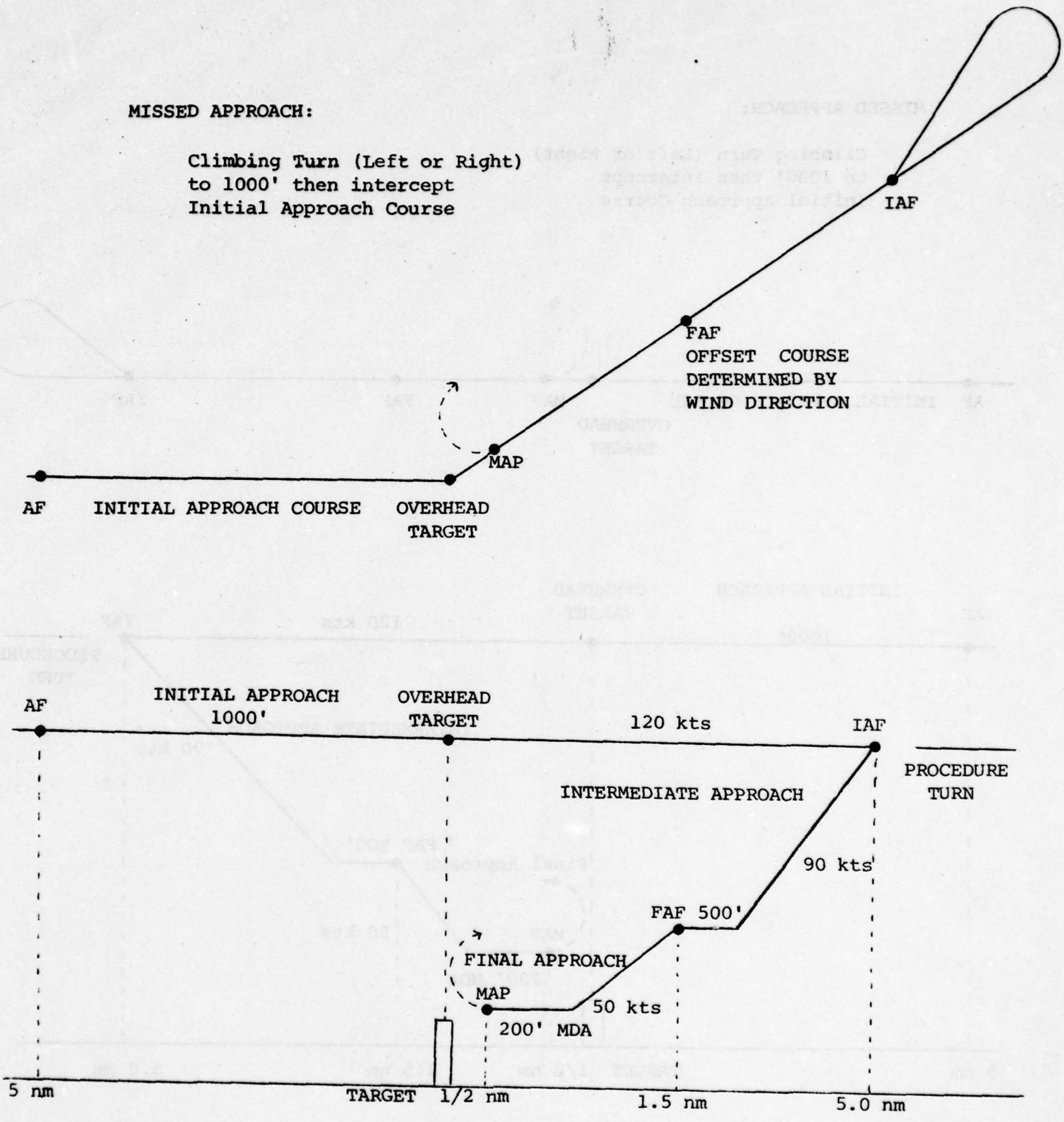


Figure 4.8 Profile 3: Overhead Offset Airport Site

MISSED APPROACH:

Climbing Turn (Left or Right) to 1000' then intercept Initial Approach Course.

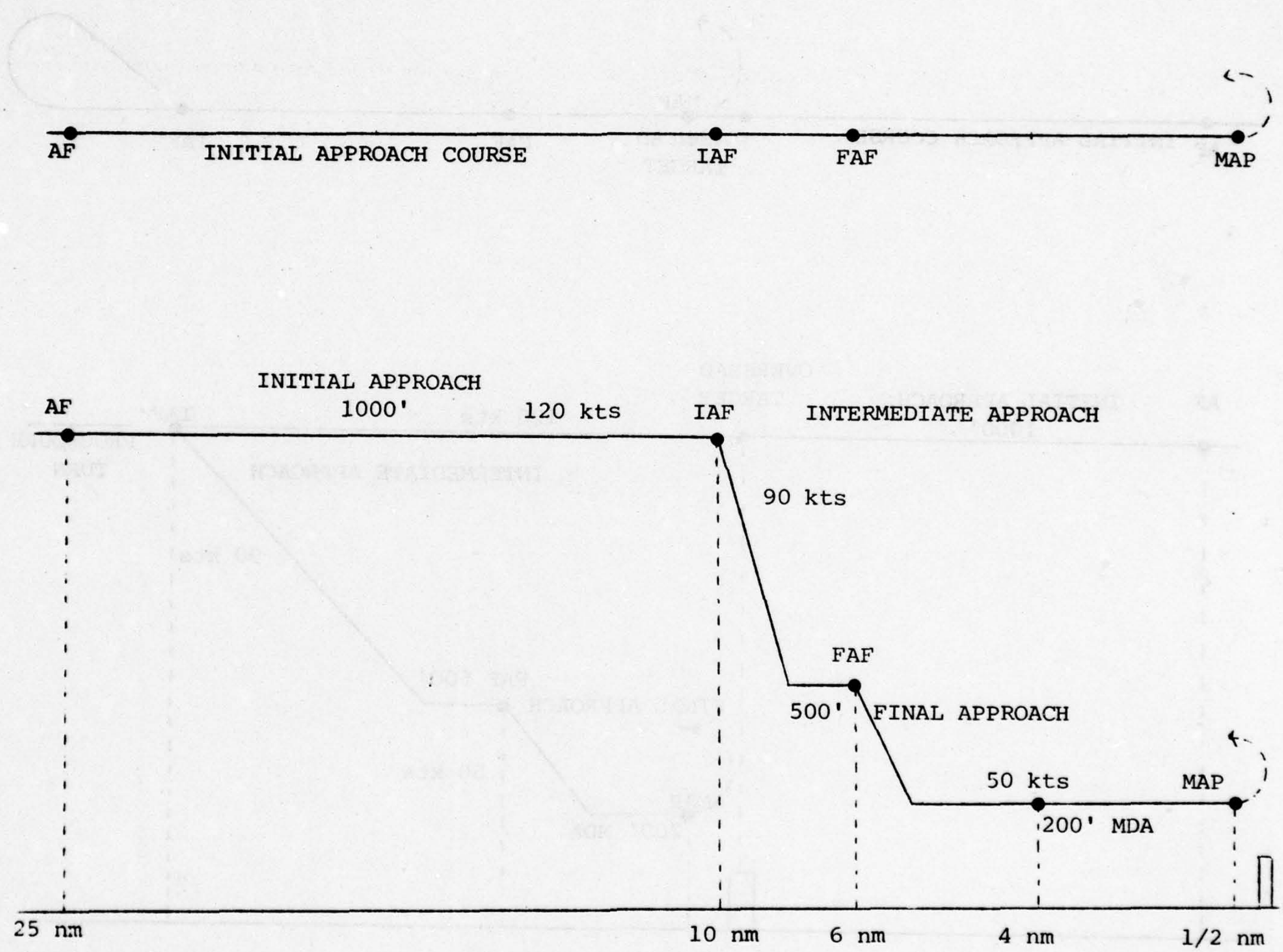
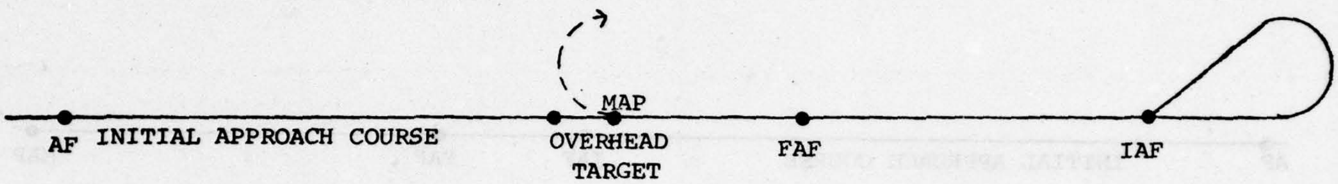


Figure 4.9 Profile 1: Direct Straight Remote And Offshore Site

MISSED APPROACH:

Climbing Turn (Left or Right) to 1000' then intercept Initial Approach Course



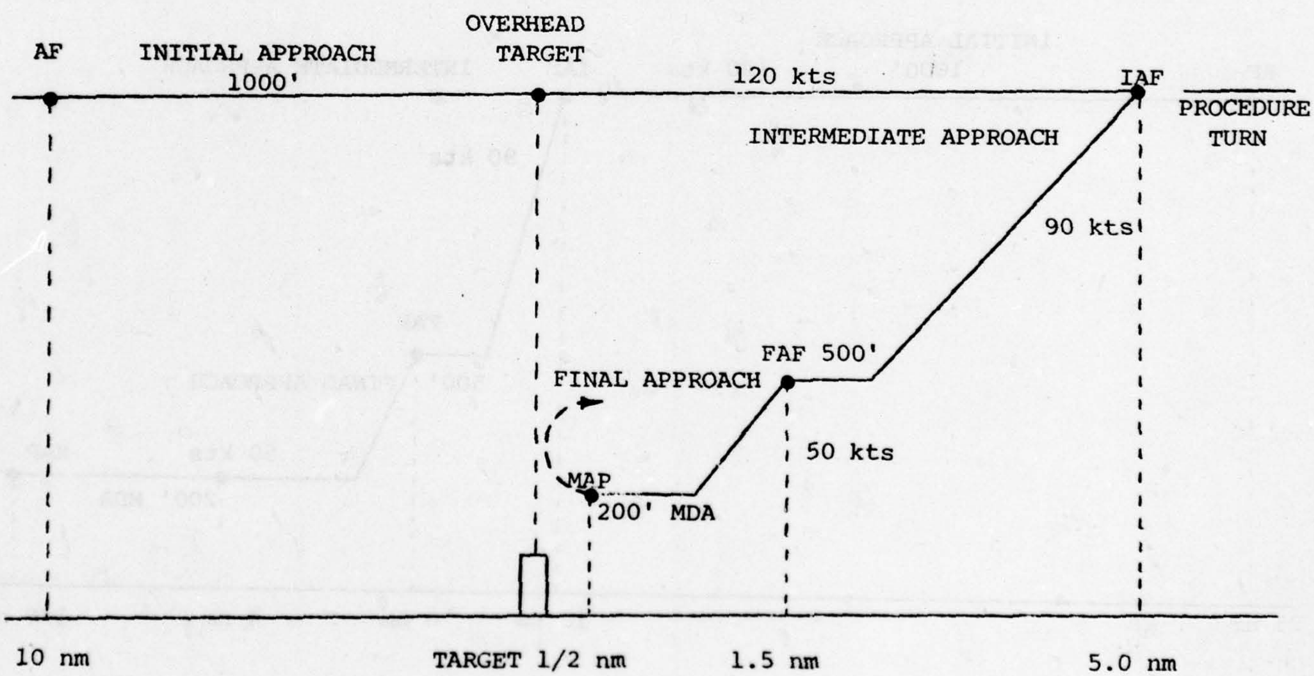


Figure 4.10 Profile 2: Overhead Straight Remote And Offshore Site

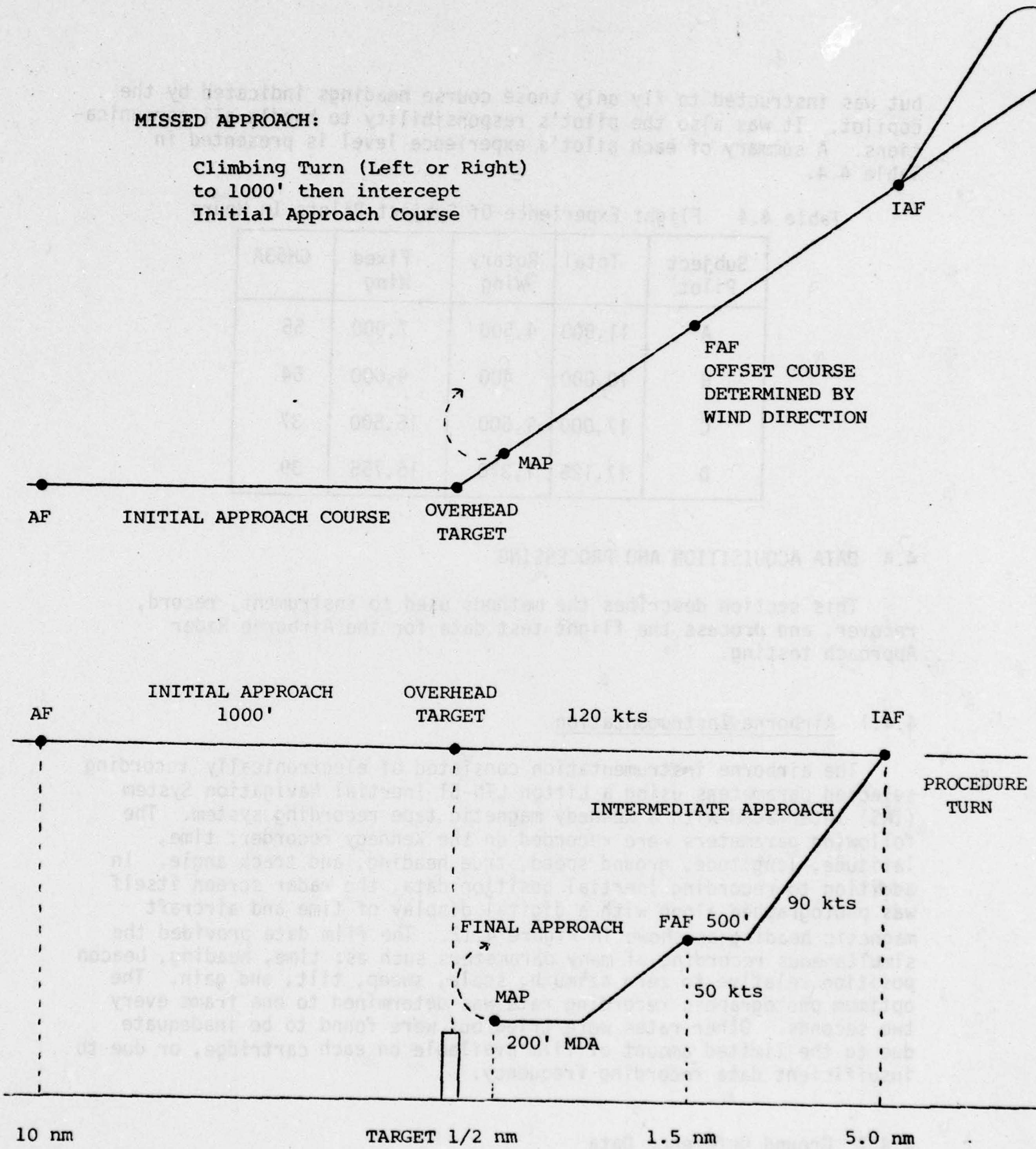


Figure 4.11 Profile 3: Overhead Offset Remote And Offshore Site

but was instructed to fly only those course headings indicated by the copilot. It was also the pilot's responsibility to handle all communications. A summary of each pilot's experience level is presented in Table 4.4.

Table 4.4 Flight Experience Of Subject Pilots In Hours

Subject Pilot	Total	Rotary Wing	Fixed Wing	CH53A
A	11,500	4,500	7,000	55
B	10,000	400	9,600	54
C	17,000	1,500	15,500	37
D	17,125	1,370	15,755	39

4.4 DATA ACQUISITION AND PROCESSING

This section describes the methods used to instrument, record, recover, and process the flight test data for the Airborne Radar Approach testing.

4.4.1 Airborne Instrumentation

The airborne instrumentation consisted of electronically recording selected parameters using a Litton LTN-51 Inertial Navigation System (INS) interfaced with a Kennedy magnetic tape recording system. The following parameters were recorded on the Kennedy recorder: time, latitude, longitude, ground speed, true heading, and track angle. In addition to recording inertial position data, the radar screen itself was photographed along with a digital display of time and aircraft magnetic heading as shown in Figure 4.12. The film data provided the simultaneous recording of many parameters such as: time, heading, beacon position relative to zero azimuth, scale, sweep, tilt, and gain. The optimum photographic recording rate was determined to one frame every two seconds. Other rates were tried but were found to be inadequate due to the limited amount of film available on each cartridge, or due to insufficient data recording frequency.

4.4.2 Ground Reference Data

The ground reference data was obtained using the NAFEC "Extended Area Instrumentation Radar" (EAIR). The EAIR radar was utilized as the indicator of actual aircraft position, by detecting and recording (real time) the azimuth, elevation and range of the test aircraft. EAIR is a precision, C-band tracking radar which provides the slant range, azimuth angle and elevation angle of an aircraft within a

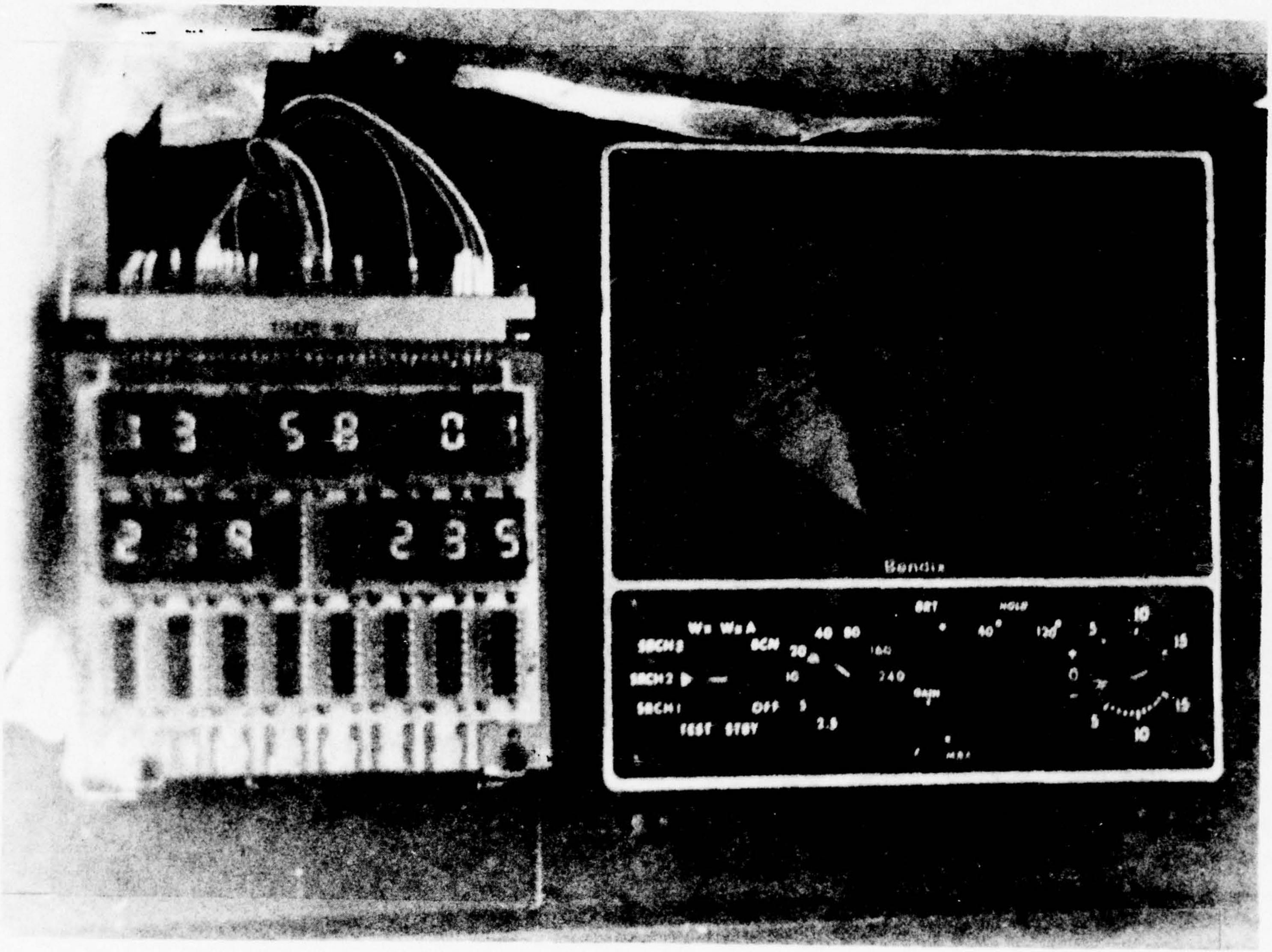


Figure 4.12 Bendix RDR-1400A Display Indicator With Digital Data Display

range of 100 nautical miles when operating in the skin tracking mode, with a maximum distance of 190 nautical miles when operated in the beacon tracking mode. (All of the ARA test flights were tracked in beacon tracking mode). The slant range obtained by the EAIR facility is accurate within 20 yards and the azimuth angle and elevation angle are accurate within 0.011 degrees. For example, at 50 miles the accuracy would be 20 yards in range and 20 yards in azimuth and elevation. The radar antenna can track a target 360° in azimuth and from 0° to +89° in elevation. The antenna can be directed as low as minus one and one-half degrees in elevation.

4.4.3 Manually Recorded Flight Logs

During all flights a trained cockpit observer monitored and kept an accurate log of routine and special events that occured during the flight. The observer was responsible for documenting the crew workload and performance. The flight logs recorded by the observer were a major source of data acquisition from which flight test results could be operationally evaluated. The following is a summary of the flight test data recorded by the observer during each flight.

1) Procedural Errors
2) Elapsed Time
3) Altitude
4) Airspeed
5) Aircraft Heading
6) Radar Approach Distance
7) Radar Mode
8) Radar Range Scale
9) Radar Gain Position
10) Radar Tilt and Stabilization
11) Pilot Workload

4.4.4 Data Processing

The airborne and ground-derived position tracking data were used to determine the capability of an airborne radar approach procedure to guide a helicopter along a predetermined approach path to a beacon. To logically evaluate this capability, the following basic group of measures were computed for each test approach:

1) Helicopter deviation from the intended track (the track to be defined by an inbound bearing to the runway threshold or landing zone).

2) Radar sensor error in both the along track and cross track directions.

3) Flight technical error (FTE) which is a measure of pilotage error in the cross track direction at all ranges

4) Letdown error (LDE) which is a measure of pilotage error in the along track direction at step down fixes.

The raw flight test data was reduced according to the following steps:

1) A projected preview of each film was performed to identify the targets, before digitization of the photographic data.

2) The relevant photographic data was then recovered by projecting the data on a digitizer tablet which was interfaced with a computer. In addition, data read from each frame such as time and heading was also inputted. The overall return dimensions were recovered wherever possible, since return size and shape played an important role in pilot orientation during each approach.

3) While digitizing, computer routines were used to convert digitized points to radar range and azimuth coordinates.

4) The file was then transmitted via dataphone to the time sharing system, where NAFEC EAIR and INS data tapes had also been sent for processing.

5) The airborne data was then merged with the tracking information to produce a complete data file from which navigation error measures were derived. EAIR tracking was the primary source of ground truth data, but on some approaches to the remote and offshore sites EAIR tracking was lost due to low altitude, in which case the INS had to be used. In those cases it was necessary to perform a three-way merge. When the three-way merge was complete, EAIR tracking dropout times were noted and these times were matched with the original EAIR tracking and INS printouts. Using these dropout times, the corresponding EAIR latitudes and longitudes were noted. In order to remove the effects of INS drift, differences in latitudes and longitudes were computed by subtracting the EAIR tracking values from the INS values.

$\Delta lat = lat\ (EAIR) - lat\ (INS)$

$\Delta lon = lon\ (EAIR) - lon\ (INS)$

These values were then supplied to the error analysis program, which used the three-way merge as the input file. This program then sequenced from EAIR to INS as the position standard at the times manually arrived at earlier. The program also makes use of the lat/lon correction factors, and interpolates linearly between the two corrections to yield a INS correction factor for each data point. When the merge was complete, navigation errors were computed. These were as follows: Total system cross track error, flight technical error, airborne system cross track error and airborne system along track error. The precise definition of these error quantities is specified in Section 4.5.1. The statistical treatment of these error quantities will be discussed in Section 5.

Observer log data as well as pilot and copilot workload ratings were also evaluated for each approach.

4.4.5 Data Processing Facilities

Data processing was accomplished using a combination of a dedicated microcomputer system resident at the SCI (Vt) facility, and a remote time-sharing system. Data was recovered using a Summagraphics digitizer tablet interfaced with a 32K Byte North Star microcomputer system. The digitized data, along with the parametric data read from each frame (time, heading, scale factor, sweep angle) keyed in from a CRT terminal, was stored on disk. Once complete files of data for each test were assembled, they were transmitted by direct computer data interchange to the CDC Cybernet system. The Cybernet was then used to load the INS and EAIR tapes, perform the merge step, and then perform the error measure derivation and statistical analysis steps.

4.4.6 Data Digitizing

To automate data recovery and reduce both the manual effort and the inherent potential for error, a digitizer tablet was used. Interfaced with a computer and using X-Y coordinates, the tablet allows direct entry of a broad range of data types (graphs, plans, maps, photographs, etc.) with a high degree of resolution. This technique was used with an image of each frame of film photographed in the ARA tests projected directly onto the tablet itself.

Exact registration with the tablet coordinate system was not necessary, and the problems associated with scale maintenance were eliminated, since the computer algorithm makes the necessary scale and registration adjustments frame by frame. For instance, several reference points on the CRT image (e.g., range marks) were first digitized by touching the tablet stylus to those several points in a pre-determined order. The computer then calculated scale and registration factors for that frame. The operator could then digitize the endpoints of the radar, resulting in accurate measures of target azimuth, range and size.

4.5 DATA ANALYSIS PROCEDURES

Based on the defined intended track, the actual range/azimuth and cross track error were computed, along with airborne system error (radar and heading sensor error), and flight technical error (FTE). The production of the measures permitted a statistical analysis of each approach segment. An overall review and statistical aggregation was the result of this data processing; also plots were generated depicting the same information represented in the statistical analysis. The sample size for these quantities was determined by the number of film data points collected. It should be noted though that some data in Section 5.0 is represented by the number of film data points collected and the number of approach segments these quantities were derived from. An outline of the data included in this report is presented in Table 4.5.

4.5.1 Navigation Error Analysis

Three measures of navigation error are desired: total system error (as measured by the EAIR and INS tracking systems), flight technical error, and airborne system (radar and heading combination) error. These quantities were calculated from the measured parameters in the following manner:

TOTAL SYSTEM ERROR -- Total system error is the deviation of the of the aircraft from desired track (in the cross track direction) as measured by the tracking system (EAIR). After appropriate coordinate conversions, actual aircraft range (r_0) and bearing to the target (θ_0) were calculated given target coordinates, intended track bearing (θ_t) and aircraft position. Total System Cross Track Error (TSCT) and Total Along Track Distance (TATD) were calculated as follows:

$$TSCT = r_0 \text{ SIN } (\theta_0 - \theta_t)$$

$$TATD = r_0 \text{ COS } (\theta_0 - \theta_t)$$

FLIGHT TECHNICAL ERROR -- FTE is defined as the <u>indicated</u> deviation from desired course in nautical miles. The radar does not directly display this value, and so the pilot must deduce the indication from available parameters:

Table 4.5 Data Processing and Analysis Outline

- **MEASURE: TOTAL SYSTEM ERROR (along track and cross track)**

  Source
  - EAIR Tracking Radar Data
  - INS Platform Data
  - Desired Track Parameters

  Presentation
  - Plots of Actual Track vs Desired Track
  - Histogram of Total System Error

  Statistical Analyses
  - Mean
  - Standard Deviation

  Applications
  - TERPS Protected Airspace
  - Comparison of Enhancement Modes

- **MEASURE: LETDOWN ERROR (along track)**

  Source
  - EAIR Tracking Radar Data
  - INS Platform Data
  - Airborne Radar Distance to Landing Zone
  - Step-down Fix Distance
  - Aircraft Altitude
  - Time Synchronization

  Statistical Analyses
  - Mean
  - Standard Deviation

  Applications
  - TERPS Fix Displacement Error

- **MEASURE: FLIGHT TECHNICAL ERROR (cross track)**

  Source
  - EAIR Tracking Radar Data
  - INS Platform Data
  - Airborne Radar Data
    - range
    - azimuth
  - Aircraft Heading
  - Aircraft Altitude
  - Time Synchronization

  Presentation
  - Plots of FTE as a Function of Range to Landing Zone
  - Histogram of Flight Technical Error

  Statistical Analyses
  - Mean
  - Standard Deviation

  Application
  - Certification Error Budget

- **MEASURE: AIRBORNE SENSOR ERROR (along track and cross track)**

  Source
  - Total System Error
  - Flight Technical Error

  Presentation
  - Plots of Sensor Error vs Range to Landing Zone
  - Histogram of Sensor Error

  Statistical Analyses
  - Mean
  - Standard Deviation

  Applications
  - Certification Error Budget

- **MEASURE: BEACON PROXIMITY DATA (range and azimuth)**

  Source
  - Airborne Range to Landing Zone
  - Beacon Presentation on Radar Display (target size)

  Presentation
  - Beacon Image Size vs Range to Landing Zone (sensitive to gain setting)

  Applications
  - Operational Evaluation of Enhanced Targets
  - Beacon Presentation Certification Data
  - Display Resolution for SC-133

- **MEASURE: AIRBORNE RADAR RANGE DATA**

  Source
  - Airborne Radar Presentation

  Presentation
  - Maximum and Minimum Airborne Range vs Site (dependent upon gain setting)

  Application
  - SC-133 Requirement and FAA Certification Specification

- **MEASURE: PILOT PROCEDURES AND BLUNDER ERROR DATA**

  Source
  - Tracking Radar Data
  - Observer Log

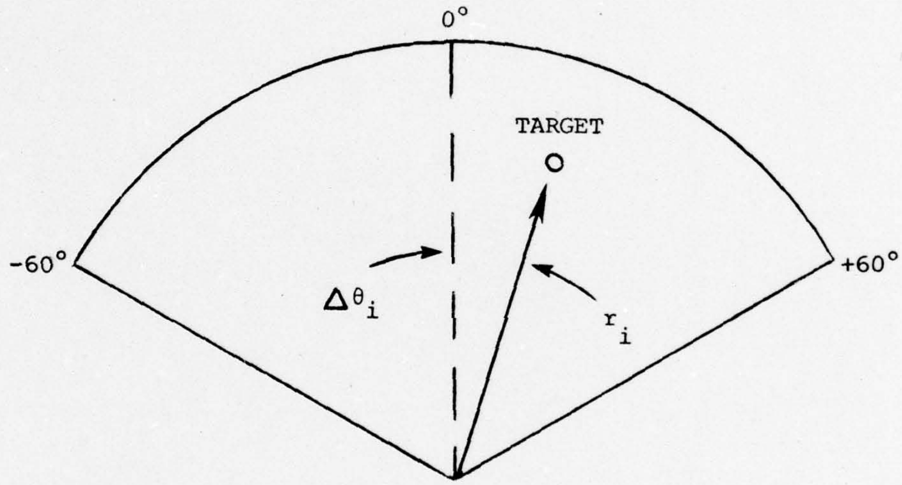
  Presentation
  - Blunder Type vs Operational Procedure
  - Count of Procedural Error and Blunder by Type

  Application
  - Workload Assessment
  - Operational Procedures Evaluation
  - TERPS Protected Airspace Requirements
  - FAA and SC-133 Specific Radar Design Requirements

radar range, (r_i) and azimuth (θ_i) to the target (landing zone) and aircraft heading (θ_h), plus knowledge of desired inbound track bearing (θ_t). Since the antenna boresight is in line with aircraft heading, indicated target azimuth (θ_i) is actually derived as being

$$\theta_i = \theta_h + \Delta\theta_i$$

where $\Delta\theta_i$ is the indicated azimuth deviation from the centerline of the display (see Figure below). The pilot tries to navigate the aircraft such that indicated target azimuth (θ_i) is equal to desired track bearing (θ_t).



When this is true the aircraft is on course. Under a zero-wind condition, if the pilot successfully acquires and flies the intended course, then $\Delta\theta_i$ will go to zero. In the presence of a cross wind, $\Delta\theta_i$ would stabilize on some finite value of crab angle if the course is properly tracked. When θ_i is not equal to θ_t, an off-course condition is indicated. The value of the FTE indication is

$$\text{FTE} = r_i \text{ SIN } (\theta_i - \theta_t) \text{ (left is +)}$$

also, $$\text{ATD} = r_i \text{ COS } (\theta_i - \theta_t) \text{ (TO is +)}$$

where ATD is along track distance to the target.

AIRBORNE SYSTEM ERROR -- Cross track and along track components of airborne system navigation error were computed from knowledge of position calculated from tracking data and the indicated position of the radar/heading combination. These errors, ASE (Airborne System Error), and ATE (Nav System Along Track Error) were calculated as follows:

ASE = TSCT-FTE
ATE = ATD-TATD

An additional error component is along track pilotage error experienced when a step down fix is crossed. Letdown Error (LDE) is defined as the difference between ATD when descent is actually initiated and the nominal along track distance of the step down fix as charted.

5.0 ANALYSIS OF RESULTS

The purpose of this section is to provide detailed insight into the flight test results and data analysis for the Airborne Radar Approach evaluation. The details presented in this section present the results of a comprehensive review of the specific data collected during the flight test program.

This section is divided into five subsections of data analysis to assist in the understanding and interpretation of the primary results. These categories are:

- 5.1 Airborne Radar As An Approach Aid
- 5.2 Development of Pilot Procedures
- 5.3 Detailed Accuracy Data
- 5.4 Operational Evaluation of the ARA Concept
- 5.5 Specific ARA Results in Various Operational Modes

Due to the fact that three test areas were involved —Airport, Remote, Offshore —and that two radar operating modes were tested—skin paint and beacon—and that three types of data are of interest—accuracy, functional and procedures —this results discussion begins in Section 5.1 with a terse summary of the major findings. This summary of results is then followed and substantiated by more detailed tabular and graphical data analysis. This data analysis has been categorized as shown above into Section 5.2, 5.3, 5.4, 5.5 for ease of reference.

5.1 AIRBORNE RADAR AS AN APPROACH AID

The results presented in the following discussion have been compiled from the overall analysis of ARA as an approach aid. The purpose of this section is to highlight the data and the quantitative results which provide the most significant impact on the qualitative conclusions reached. To this end, Section 5.1.1 discusses primary results developed in detail in Section 5.2. Similarly, Section 5.1.2 summarizes Section 5.3 etc.

5.1.1 Analysis of Pilot Procedures

Pilot ARA procedures were developed which resulted in safe approaches with acceptable cockpit workload. These procedures were compatible with current ATC operational constraints in the airport, remote and offshore areas. The procedures developed were partially conceptual and partially empirically derived. The conceptual aspects included utilizing one of three basic flight profiles to perform the approach. These were the direct straight, overhead straight and overhead offset profiles. The utilization of these three alternative flight profiles provided in-flight approach procedures that were easily adaptable to existing meteorological conditions at the landing site. These alternative procedures minimized cockpit workload and resulted in reduced pilot/copilot confusion levels.

The empirical aspects of the ARA approach procedures were in the area of pilot/copilot responsibility assignments. After experimenting with single vs two-pilot operations and various workload splits between navigation, communication, flight control and flight safety, the following ARA crew workload assignments were found acceptable:

1) The pilot was given primary responsibility for flight control and safety of flight.

2) The pilot was assigned radio communications duties.

3) The copilot was solely in charge of ARA navigation.

4) The copilot was responsible for interpreting the radar and communicating required headings, heading changes, altitudes and airspeeds to the pilot.

These crew coordination procedures combined with the flight profile procedures resulted in a calm and coordinated cockpit environment. These procedures also insured maximum obstruction clearance while meeting most required test objectives. In summary, the flight procedures were simple, offered a considerable amount of versatility and integrated well with the operational ATC system.

5.1.2 Overall Accuracy Assessment

The detailed ARA accuracy data is presented and analyzed in Section 5.3. This section summarizes ARA accuracy using three levels of analysis. First, overall ARA accuracy statistics are presented for the four primary error measures. These measures are Total System Cross Track Error (TSCT), Flight Technical Error (FTE), Airborne System Error (ASE) and Along Track Error (ATE). These error quantities have been defined previously in Section 4.5. Second, error statisitcs are analyzed with respect to along track distance from the target landing zone. These errors are quantified in linear and angular terms. Third, an overall operational assessment of ARA errors is made using TSCT, FTE, ASE and ATE values along with qualitative interpretation of their significance.

Table 5.1 summarizes the mean and one-sigma ARA error quantities obtained during the flight tests. The data in the table includes all airport approaches flown regardless of the approach procedure. Section 5.2 discusses the details of long, short and offset approach procedures.

Table 5.1 Overall Airport ARA Performance Summary

Error Quantity	Error Magnitudes	
	Mean nm	$\pm 1\sigma$ nm
TSCT	0.52	1.31
FTE	0.56	1.38
ASE	-0.04	0.45
ATE	0.12	0.17

Inspection of Table 5.1 results in several conclusions. First, the ARA TSCT and FTE obviously behave differently than the ASE and ATE. That is, the ARA system related errors (ASE and ATE) are much less than those errors involving the human pilot (FTE and TSCT). This is due to the observation that the ARA pilots had some difficulty in precisely interpreting the displayed relative position information and translating that into course corrections. The result (which shows up in TSCT and FTE) was that the radar approach was executed in a "homing" fashion rather than a cross track guidance and along track guidance fashion. Second, these observed TSCT errors, although large (±2.6 nm two sigma), were well within the ±4.0 nm accuracy specified in the current SC-133 MOPS.

Examination of the detailed data of Seciton 5.3 also reinforced this homing characteristic. For the long approaches with segment lengths greater than ten nautical miles, TSCT and FTE one-sigma errors were ±1.8 nm and ±1.9 nm respectively. In contrast, for the short and offset approaches with segment lengths less than ten nautical miles, TSCT and FTE were always less than ±0.75 nm.

In the analysis of error quantities with respect to along track distance, both linear and angular magnitudes were examined. The general observation was made that large angular errors occurred close-in on the approach due to the cross track bias errors which approached ±1.0 nm at small distances from the missed approach point (MAP). The angular TSCT data from ten nautical miles out to the target varied between 5°-10° until the three mile point was reached. From three nautical miles to the target the angular error increased rapidly.

Table 5.2 illustrates the behavior of both angular and linear errors within the three mile distance-to-go area. The most obvious fact observable in this table is that both TSCT and FTE linear errors were acceptably small (±0.6 to ±0.7 nm) in the 1-3 nm along track region. However, due to the proximity to the target, these small cross track errors produce large (±11.0° to ±33.0°) angular errors. There was an operational reason for these relatively large errors close-in. Due to the number of relatively short (5 nm) approaches, some of the procedure turns that the pilots used to acquire the inbound course were downwind, which caused the aircraft to be blown considerably off course. Even so, all TSCT (one-sigma) errors would be included in a ±30° cone with its origin at the MAP.

Table 5.2 ARA Airport Angular and Linear Errors As A Function of Along Track Distance

Distance From BCN	One Sigma ARA Error Quantities							
	TSCT		FTE		ASE		ATE	
	nm	deg	nm	deg	nm	deg	nm	deg
1 nm	±0.6	±29.7	±0.6	±32.3	±0.1	±5.2	±0.1	N.A.*
2 nm	±0.6	±17.7	±0.7	±20.4	±0.2	±4.5	±0.1	N.A.
3 nm	±0.6	±11.4	±0.6	±11.7	±0.1	±2.7	±0.1	N.A.

*NA - Not Applicable

The overall assessment of ARA operational performance in the airport environment was that it was quite acceptable. Obstacle clearance airspace limits were considerably conservative and could easily be satisfied using the ARA system. Maximum TSCT errors in the 5-10 nm from the target area were ±2.5 nm compared to a stated requirement of ±4.0 nm, established by RTCA SC-133 MOPS, in this area. Maximum TSCT errors within five miles were ±1.3 nm compared to a ±1.7 nm requirement. These acceptable performance levels were attained even with the large FTE errors incurred outside the ten mile point due to track acquisition procedures. ASE error quantities were all acceptably small and did not adversely impact TSCT or FTE.

ARA problems which affected TSCT and FTE were associated primarily with interactions between the dynamic response of the aircraft's heading compared to the update rate of the radar and the radar "jitters" described in Section 5.3.

In the remote site approach testing, data similar to the airport results were obtained. Table 5.3 summarizes the overall remote site ARA performance and may be compared directly to Table 5.1.

Table 5.3 Overall Remote Site ARA Performance Summary

Error Quantity	Error Magnitudes	
	Mean nm	$\pm 1\sigma$ nm
TSCT	0.32	0.82
FTE	0.45	0.80
ASE	-0.14	0.43
ATE	-0.06	0.22

Inspection of Table 5.3 shows that all mean errors were comparable to the airport site data and that TSCT and FTE one-sigma errors were somewhat lower for the remote site (±0.8 nm remote compared to ±1.3 nm airport). This improvement in ARA performance at the remote site was attributed to the inflight procedural differences. The remote site approaches were performed by flying from NAFEC direct to the remote site (no procedure turn). The airport testing required a departure from NAFEC followed by a procedure turn and then an approach to NAFEC. The remote site data confirms the fact that the procedure turns inflated the TSCT and FTE airport data. The remote site data suggests that direct-to procedures to an initial approach fix are highly desirable.

Table 5.4 summarizes the remote site linear and angular errors as a function of distance from the target landing zone. The ARA error magnitudes expressed in this form further substantiate that the remote site approaches were more accurate. That is, the TSCT one-sigma data at the airport (Table 5.2) was a constant ±0.6 nm while the remote site data starts at ±0.6 nm and decreases to ±0.3 nm at one nautical mile from the target. FTE error magnitudes behave similarly. This more accurate data is also

attributed to the lack of a procedure turn. The continued reduction in TSCT and FTE illustrate the pilot's "homing" technique using airborne radar as an approach aid. The ASE and ATE linear errors are not significantly different from the airport data. In addition, the ASE and ATE values at both the remote site and the airport are very small. This indicates that the airborne radar is both reliable and repeatable.

Table 5.4 ARA Remote Site Angular and Linear Errors As A Function of Along Track Distance

Distance From BCN	One Sigma ARA Error Quantities							
	TSCT		FTE		ASE		ATE	
	nm	deg	nm	deg	nm	deg	nm	deg
1 nm	±0.3	±17.0	±0.3	±16.9	±0.3	±16.0	±0.2	N.A.*
2 nm	±0.5	±13.9	±0.5	±12.9	±0.3	± 8.3	±0.2	N.A.
3 nm	±0.6	±11.9	±0.6	±11.7	±0.3	± 5.4	±0.2	N.A.

*NA - Not Applicable

The offshore ARA testing was conducted using Brandywine Lighthouse located in Delaware Bay. These tests were performed using the beacon mode of radar operation. Table 5.5 summarizes the overall TSCT, FTE, ASE and ATE errors measured during the offshore tests. As shown in the table, these results were not significantly different from the remote site overall statistics. That is, the TSCT and FTE one-sigma values are very close in magnitude. The ASE and ATE values are much smaller than the TSCT and FTE errors. Also, the offshore results for TSCT and FTE more closely match the remote site than the airport data. This further substantiates the difference between flying an approach direct to an IAF and flying a procedure turn as was the case in the airport data.

Table 5.5 Overall Offshore ARA Performance Summary

Error Quantity	Error Magnitudes	
	Mean nm	$\pm 1\sigma$ nm
TSCT	-0.29	0.92
FTE	-0.07	1.03
ASE	-0.22	0.52
ATE	-0.001	0.24

Table 5.6 presents the performance of the ARA as a function of distance from the target. This data shows the same characteristic homing effect in TSCT and FTE, with one-mile data at ±0.3 nm for both errors. These numbers have been rounded to the nearest one-tenth of a nautical mile to reflect measurement accuracy. The angular TSCT and FTE values were ±18.9° and ±15.5° respectively. ASE and ATE linear errors were identical to the remote site. Angular ASE was ±9.1° at the one nautical mile point.

Table 5.6 ARA Offshore Angular and Linear Errors As A Function of Along Track Distance

Distance From BCN	One Sigma ARA Error Quantities							
	TSCT		FTE		ASE		ATE	
	nm	deg	nm	deg	nm	deg	nm	deg
1 nm	±0.3	±18.9	±0.3	±15.5	±0.2	±9.1	±0.2	NA*
2 nm	±0.6	±15.9	±0.5	±14.8	±0.2	±4.3	±0.2	NA
3 nm	±0.8	±14.6	±0.8	±14.2	±0.2	±3.7	±0.2	NA

*NA - Not Applicable

In summary, the overall accuracy assessment of the ARA data showed that all performance measures fell within acceptable limits as defined by the RTCA SC-133 airspace requirements. In particular, the ability of the crew to stay within specified obstacle clearance limits (as measured by tracking radar) was shown to be acceptable and repeatable. The error quantity used to measure this performance was TSCT. Summary data for TSCT one-sigma errors for the three test areas were as follows:

TSCT $\pm 1\sigma$	TEST AREA
1.31 nm	Airport
0.82 nm	Remote
0.92 nm	Offshore

This performance is acceptable compared to current Minimum Operational Performance Standards specified in the RTCA SC-133 document.

In addition to these overall aggregate statistics, the behavior of an aircraft/pilot using ARA procedures was quantified in angular and linear terms as a function of distance from the target landing zone. This data showed that TSCT and FTE errors reflected the tendency to use ARA as a homing device rather than a cross track error "nulling" device. The angular errors for TSCT and FTE varied from 11° at 3 nm from the target to 33° at the 1 nm point. The error values of 30° and greater were all measured during the airport testing and were attributed to the procedure

turn approach technique utilized. The offshore and remote angular errors for TSCT and FTE were constrained within 11°-19°. This was characteristic of the direct-to approach procedure utilized. Table 5.7 summarizes linear and angular errors at the one nautical mile distance from the target for the three test regions.

Table 5.7 ARA Linear and Angular One-Sigma Error Summary At 1 nm From the Target

TEST AREA	TSCT		FTE	
	Linear nm	Angular deg	Linear nm	Angular deg
Airport	±0.6	±29.7	±0.6	±32.3
Remote	±0.3	±17.0	±0.3	±16.9
Offshore	±0.3	±18.0	±0.3	±15.5

Table 5.7 illustrates that although the angular errors close to the target were quite large, the linear error magnitudes did not exceed specified accuracy limits and were considered acceptable. Table 5.7 also quantifies the difference between ARA performance for straight in approaches (±0.3 nm) compared to ARA approach accuracy using procedure turn techniques (±0.6 nm). Finally, the maximum errors using the ARA approach system were also evaluated and found to be well within the specified obstacle clearance limits established by RTCA SC-133 MOPS.

5.1.3 ATC Integration

An operational evaluation of the ARA concept in today's ATC environment was also performed. Section 5.4 discusses this analysis in detail for landside (airport and remote sites) as well as offshore ATC procedures. A summary of this analysis is presented in this section.

The net result of the operational evaluation of the ARA concept in the ATC environment was that it is a practical and usable solution to providing non-precision approach capabilities where other navigation aids are unavailable. This conclusion applies to all three approach regions investigated. Although current ARA ground and airborne equipment performed acceptably during these tests, operational utilization in the day-to-day ATC environment would benefit from several ARA system enhancements. First, the ground based equipment could be improved in both signal strength and reliability. Second, more advanced radar features are highly desirable to reduce crew workload and improve the safety of the ARA concept. These improvements are in the areas of automatic gain control and tilt control, variable gain beacons and improved display characteristics. Third, formal crew training procedures and requirements must be developed. With these modifications, the ARA system can provide ATC compatible performance which exceeds the experimental performance at airports, remote sites and offshore.

In the airport area, an ARA approach closely parallels the standard NDB non-precision approach technique in both workload and accuracy. As with any approach, the pilot's proficiency directly impacts both accuracy and operational ATC compatibility. The experimental airport data showed lateral accuracy well within current landside lateral obstacle clearance minima. However, current ARA lateral obstacle clearance limits established by RTCA SC-133 MOPS exceed NDB and other non-precision approach values. This could possibly lead to higher ARA minimum descent altitudes. From an ATC integration viewpoint, high altitudes and larger lateral obstacle clearance minimums require more airspace. This could limit the areas where ARA would be usable or it could necessitate special approach procedures, such as the point-in-space approaches, to congested terminal areas where adequate approach airspace was not available to the active runway. Airport ARA approaches also require positive navigation when flying to the Initial Approach Fix. This could translate into a requirement for beacons on the ground or some additional airborne navigation equipment (such as the RNAV system used for these tests). Even with these additional navigation aids, multidirectional ARA procedures at airports will require careful planning and a high degree of pilot proficiency to achieve the desired accuracy.

At remote sites, ATC integration takes on diminishing importance. However, it is necessary to be able to fly to the remote site and make an approach without disrupting enroute flight paths of other aircraft or interfering with local area arrival and departure procedures at nearby airports. The test data collected showed that remote site ARA flights could operate satisfactorily under these constraints. The ARA system provides the operator with a non-precision approach capability which does not currently exist in remote areas where other navigational aids are not available. The ARA approach accuracy at the remote site was well within acceptable obstacle clearance limits.

In the offshore ARA tests, three operational ATC considerations are paramount. First, the ARA system and procedures must provide accurate and repeatable guidance to an IAF in the vicinity of the offshore target. Second, the ARA system must provide adequate guidance in a controlled descent to the specified minimums while providing adequate obstacle clearance. Third, the ARA procedures must provide a simple and safe missed approach procedure in the vicinity of a multitude of prominent surface objects. The ARA system tested satisfied all of the above operational criteria when operating in the beacon mode. It is again necessary to stress the need for a high degree of pilot training and proficiency in order to achieve this acceptable performance.

5.1.4 Attributes of Alternative Operating Modes

Up to this point, ARA performance has been analyzed as a function of operating environment and airborne procedures. This section summarizes the data presented in detail in Section 5.5 regarding skin paint compared to single beacon operating modes.

Operationally, the skin paint mode provides positive guidance to reflectors or prominent surface objects without relying on a powered beacon.

This eliminates the failure of the ARA concept due to loss of a ground based signal. If these skin paint targets can be positively identified, then the ARA approach accuracy could match the beacon mode. The major operational problem lies in obtaining sufficient useful knowledge of the local area (in the ARA approach path) to decipher correctly and repeatably (from all approach angles) which skin painted target represents the primary target for the approach. If procedures and training can be developed to insure this positive identification, then repeatable and accurate ARA approaches can be made in the skin paint mode. This mode offers the additional advantage of providing detailed knowledge of obstacles surrounding the approach path and the intended target.

The single beacon mode provides approach accuracies similar to those discussed previously for airport, remote and offshore applications. Operationally, this mode depends on a valid and repeatable beacon signal. If there is no signal, the approach cannot be made. The angular and linear error quantities in the single beacon mode are identical in both magnitude and behavior to those previously discussed. Graphic illustrations are presented in Section 5.5 which demonstrate the behavior of ATE, ASE, TSCT and FTE with respect to specific limits. Basically, the ATE and ASE errors are independent of range from the target while TSCT and FTE exhibit the "homing" characteristics previously discussed. Histograms of these error quantities show that ATE and ASE are very peaked compared to a normal distribution but with near zero means. TSCT and FTE error distributions are nearly normal but skewed to the right.

Finally, the size of the single beacon return is analyzed in Section 5.5 as a function of distance from the target. A mean value of 13.2° with a one-sigma of ±4.1° was obtained. The magnitude of target width was independent of range from the target.

5.2 DEVELOPMENT OF PILOT PROCEDURES

The Airborne Radar Approach pilot procedures were designed with three concepts in mind.

- Provide procedures that offer a minimum cockpit workload.
- Provide procedures that integrate well with ATC.
- Offer to the pilot procedures that are flexible yet result in the safe conduct of the approach.

A detailed description of the pilot and copilot procedures utilized during the flight test was given in Section 4.2.2.

Since the flight test was experimental in nature, in the early phases of the testing formal pilot procedures were not yet developed. In early testing several combinations of pilot and copilot duties were investigated. During the skin paint testing some approaches were flown solely as a single pilot operation. This procedure was found to be inadequate due to the extremely high workload experienced by the pilot.

To achieve the first goal of minimum cockpit workload it was decided to conduct the remainder of the tests using two pilots. After the decision was made to use two pilots it was then necessary to design procedures to meet the three objectives mentioned earlier. Since the one-pilot operation turned out to be infeasible, the workload then had to be divided between the two pilots.

To alleviate cockpit confusion the copilot was given the sole responsibility of navigator, while the pilot was in charge of the aircraft's safe operation. In addition, for safety reasons it was decided to only have the copilot hooded, while the pilot remained unhooded. Each pilot and copilot was briefed before each flight concerning the procedures to be flown that day. In the early phases of the flight test these procedures were changed considerably to suit the need of the crew and ATC. After a fixed set of procedures was established, before each briefing the flight test observer determined the procedures to be flown.

To provide procedures that offer a minimum cockpit workload required a full understanding of all phases of the approaches. On some of the early single beacon approach testing the copilot was given the dual duties of navigator and communications operator. It was then the pilot's responsibility to fly the aircraft according to those headings, heading changes, altitudes, and airspeeds given by the copilot. At first this procedure worked well, but a careful evaluation revealed the copilot often times concentrated too much on the communications aspect and not enough on navigation. Therefore, responsibility for ATC communication was given to the pilot, leaving the copilot more time to concentrate on navigation. This procedure worked well and was utilized throughout the remainder of the testing. As presented in Section 4.2.2 the copilot's responsibility as navigator was quite extensive. The pilot's job also required a considerable amount of responsibility, but it was found that the division of workload, as mentioned above, resulted in a calm and coordinated crew environment.

The procedures utilized also integrated well with the Air Traffic Control (ATC) environment. The three profiles flown (direct straight, overhead straight, and overhead offset) offered a considerable amount of versatility depending on wind conditions. The attempt was to provide approach procedures that would best fit the meteorological conditions of the day. This resulted in a low confusion level, always letting the pilots take maximum advantage of the conditions that day. It should be noted that the ATC problems encountered usually occurred at the airport site only, since the remote and offshore sites offered little or no conflicting traffic. Section 4.2.2 summarizes in detail the approach profiles flown at each site.

The above considerations resulted in a set of procedures that were considered safe in the conduct of each approach. The altitudes and approach paths chosen assured the crew of maximum obstruction clearance, while meeting all of the required test objectives. At first the profiles for all the sites were exactly the same. After conducting a few practice approaches

at the airport site it was concluded that the six nautical mile final approach fix resulted in flying 200 feet over a very high tree line. To alleviate this problem the FAF was moved in so that it was two nautical miles from the target instead of six. Also because of noise considerations the initial plan of using NAFEC's runways 17 and 35 was changed to runways 08 and 26. A close look at this procedure also revealed that this change resulted in a greater obstruction clearance. All of the above items resulted in a flight test program that offered safe and efficient procedures for all flight test personnel.

5.3 DETAILED ACCURACY DATA

The purpose of this subsection is to provide detailed insight into the flight test results and data analysis for the Airborne Radar Approach flight testing of the Bendix RDR-1400A airborne radar. The details presented in this subsection represent the results of a comprehensive review of the specific data collected during the Airborne Radar Approach flight test program. The data is presented in three different forms. They are as follows:

- Statistical summary tables showing mean and standard deviation of four error quantities.
- Statistical summaries of data aggregated at one nautical mile intervals along the approach path.
- Plots of Total System Cross Track (TSCT), Flight Technical Error (FTE), and Airborne System Error (ASE), versus along track position of the helicopter.

5.3.1 Airport Site Accuracy Data

Table 5.8 summarizes the results of the Airborne Radar Approach testing conducted at the airport site. The error analysis log and statistical summary of error quantities in the table presents the mean values, standard deviations and the number of data points for four specific error quantities: ARA along track (ATE), ARA cross track (ASE), flight technical error (FTE), and total system cross track (TSCT).

Table 5.8 shows in the ARA ATE case that the calculated mean is .12 nm and the sigma is .17 nm for all of the approach segments. The results for ARA ASE were a total mean value of -.04 nm, and a one-sigma value of .45 nm. It should be noted that these results were derived from a very large sample size (623 data points). This increases the confidence level in the results obtained.

The Flight Technical Error (FTE) quantities indicated in Table 5.8 showed a mean value of .56 nm and a one-sigma of 1.4 nm. It is interesting to note that the FTE and TSCT values are quite similar in magnitude. The TSCT values show a mean value of .52 nm and a one-sigma of 1.3 nm. The

Table 5.8 NAFEC ARA Single Beacon Airport Approaches Error Analysis Log and Statistical Summary

IDENTIFIED	RWY	TRUE HDG	SEGMENT	OFFSET
11/03/78-1 INITIAL	26	253	LONG	
11/03/78-1 FINAL	08	043	SHORT	Yes
11/03/78-2	08	043	SHORT	"
11/03/78-3 INITIAL	08	073	LONG	
11/03/78-3 FINAL	26	283	SHORT	Yes
11/03/78-4	26	283	SHORT	"
12/13/78 pm-1 INITIAL	26	253	LONG	
12/13/78 pm-1 FINAL	08	073	SHORT	
12/13/78 pm-2 INITIAL	26	253	SHORT	
12/13/78 pm-2 FINAL	08	073	SHORT	
12/13/78 pm-3 INITIAL	08	073	LONG	
12/13/78 pm-3 FINAL	26	253	SHORT	
12/14/78-4 INITIAL	08	073	SHORT	
12/14/78-4 FINAL	26	253	SHORT	
12/14/78-5	26	253	SHORT	

	$\overline{X}$ (nm)	σ(nm)	DATA POINTS	APPROACH SEGMENTS
ARA ATE				
Long	.1209	.2349	263	4
Short	.1131	.1112	294	7
Offset	.1409	.0860	66	4
TOTAL	.1202	.1731	623	15
ARA ASE				
Long	.0168	.6336	263	4
Short	-.1200	.2324	294	7
Offset	.1140	.2271	66	4
TOTAL	-.0375	.4548	623	15
FTE				
Long	.8908	1.9144	263	4
Short	.3927	.7203	294	7
Offset	.0103	.5309	66	4
TOTAL	.5603	1.3826	623	15
TSCT				
Long	.9076	1.8025	263	4
Short	.2727	.6402	294	7
Offset	.1038	.6091	66	4
TOTAL	.5228	1.3081	623	15

cross track values are small in relation to the primary airspace requirement of ±4 nm specified in the draft Minimum Operational Performance Standards (MOPS) set by RTCA SC-133. Since the Airborne System Errors (ASE) are quite small as shown by the ARA ATE and ARA ASE values, the FTE and TSCT quantities show that the pilot tended to home to the target rather than to fly the intended track to the target. The major error resulted from the pilot's inability to correctly interpret the information displayed on the radar and to fly the intended course.

In Table 5.8 the approaches were aggregated according to three segment types: long, short, and offset. The long segments are generally those greater than or equal to ten nautical miles from the target. The short and offset segments are less than or equal to five nautical miles. The approaches were aggregated in this way so that a close look could be taken at Airborne Radar Approach Airspace considerations.

Table 5.9 summarizes in statistical quantities the Airborne Radar Approach test data at one nautical mile intervals, starting at ten nautical miles. These quantities were calculated in both linear and angular terms. Starting at four nautical miles from the target the angular FTE quantities become large. At one nautical mile the FTE mean is -.30 degrees and the one-sigma value is 32.3 degrees. The large one-sigma FTE can be attributed to fact that on three of the approaches the pilot missed the target by .8 of a nautical mile. Though .8 of a nautical mile is not of itself a large linear number, in angular terms it becomes quite large because the along track distance is so small. The TSCT numbers once again correlate very closely to the FTE quantities. At seven nautical miles the TSCT and FTE, in both linear and angular terms, are significantly large compared to other sigma values in that region. For example, the linear TSCT sigma is 1.3 nm and the FTE is 1.3 nm. These values are large because in a number of the short (5 nm) approaches the procedure turns that allowed the pilots to get established on their inbound track were made downwind, therefore blowing the aircraft considerably off course. When the procedure turn was executed downwind, very often the aircraft was blown so far off course it was difficult to acquire the intended track with any degree of accuracy. The five mile point data shows an ARA ATE mean value of .15 nm and a one-sigma of .11 nm. The ARA ASE numbers yield a mean value of -.01 nm and a one-sigma of .29 nm. The FTE and TSCT quanities are quite good at the five mile point: means of .12 and .11 nm and one-sigmas of .64 and .69 nm, respectively.

Table 5.10 summarizes the mean and one-sigma Letdown Error (LDE) quantities obtained during the single beacon approach testing conducted at the airport site. These values quantify the ability of the pilot to utilize the ARA system to define and identify a step-down fix. Table 5.10 represents values sampled at the 5.0 nautical mile Initial Approach Fix (IAF) and at the 1.5 nautical mile Final Approach Fix (FAF). The profiles shown earlier in Section 4.2 indicate that at the IAF the pilot initiated a descent from 1000 feet to 500 feet and at the FAF he initiated a descent from 500 feet to 200 feet. The error quantities were determined by correlating the airborne radar's indicated approach fix position with time. Next, using the EAIR tracking data printout it was then determined when a descent was actually initiated and this time was noted. Then the

Table 5.9 ARA Airport Single Beacon Approach Data Aggregated at One Nautical Mile Intervals

		I-----------LINEAR	ERRORS--------------	-------------I	----------	----------ANGULAR	ERRORS----------I		
NM	PTS	ATE	TSCT	FTE	ASE	TSCT	FTE	ASE	
1	12	.1384	-.0014	-.0052	.0038	-.0824	-.2988	.2164	MEAN
		.0936	.5714	.6314	.0908	29.7431	32.2679	5.1893	STD
2	15	.1206	-.0278	.0453	-.0731	-.7962	1.2964	-2.0919	MEAN
		.0771	.6381	.7444	.1580	17.6954	20.4163	4.5159	STD
3	13	.1451	-.0912	-.0592	-.0319	-1.7407	-1.1312	-.6099	MEAN
		.0957	.6063	.6215	.1393	11.4257	11.7038	2.6588	STD
4	13	.1630	.0205	.0130	.0076	.2944	.1857	.1087	MEAN
		.1696	.6443	.6860	.2328	9.1498	9.7319	3.3305	STD
5	12	.1472	.1105	.1173	-.0069	1.2659	1.3444	-.0786	MEAN
		.1051	.6880	.6417	.2873	7.8346	7.3137	3.2889	STD
6	10	.1395	.3311	.3720	-.0409	3.1586	3.5474	-.3901	MEAN
		.1105	.8385	.9114	.4079	7.9556	8.6374	3.8892	STD
7	5	.1025	.3764	.4975	-.1211	3.0780	4.0655	-.9912	MEAN
		.1173	1.2618	1.3004	.2428	10.2185	10.5237	1.9862	STD
8	4	.1321	.0534	.0204	.0330	.3824	.1460	.2364	MEAN
		.0768	.8190	.7046	.2996	5.8451	5.0330	2.1445	STD
9	4	.1149	.2144	.0448	.1696	1.3645	.2850	1.0796	MEAN
		.0717	.8211	.8544	.2402	5.2126	5.4230	1.5290	STD
10	4	.0862	.4444	.5907	-.1462	2.5447	3.3803	-.8378	MEAN
		.0811	.7985	.7831	.3012	4.5652	4.4776	1.7253	STD

latitudes and longitudes for both times were recorded and distance was computed. (Distance to the target was computed as positive). The mean value at the IAF shows that the pilot initiated his descent .36 nm after passing the fix. The mean value at the FAF shows that the pilot initiated his descent .18 nm after passing the fix. The one-sigma values show .22 nm and .20 nm quantities, respectively. It is interesting to note that the values at the FAF are less than those at the IAF indicating that either the pilot is more aware of his position close-in or that the increased display resolution at the smaller scale (i.e., 2.5 -.5) enhances the pilots ability to more accurately determine his position.

Table 5.10 Airport Site Letdown Error Quantities

APPROACH Position	ERROR MAGNITUDES	
	Mean nm	$\pm 1\sigma$ nm
IAF (5.0 nm Fix)	.3625	.2167
FAF (1.5 nm Fix)	.1812	.1951

Figure 5.1 summarizes in graphical form the total system error of all the approaches flown at the airport site. The plot shows that between five and ten nautical miles from the beacon the maximum deviation from intended track is -2.5 nm. This quantity is well within the four nautical mile airspace requirement established by the RTCA SC-133 MOPS. In most cases, with the exception of three, the pilot always verified the target location and proceeded directly towards it. Within five nautical miles the maximum deviation from intended course is -1.3 nm, which again is within the required airspace limits of ±1.7 nm at the Missed Approach Point (MAP) set by the RTCA SC-133 MOPS. To reinforce the issue even more, the three approaches that missed the MAP only had a maximum deviation of ±.95 nm.

Figure 5.2 is a plot of flight technical error (FTE) vs. distance along the desired track, for all the approaches flown at the airport site. Some of the error quantities are quite large, but it should be noted that the quantities that are large all lie outside of the ten nautical mile region. The ten nautical mile region is significant because within this area care must be taken to provide sufficient lateral obstruction clearance. The reason for the large errors outside of the ten nautical mile region are due mainly to the procedures that were followed in order to initially acquire the intended track. RNAV waypoints were used as fixes to position the pilot on track, but the inaccuracies in this particular RNAV system resulted in erroneous track intercepts. Also, as mentioned earlier, when procedure turns were executed they were sometimes executed downwind instead of upwind. On one particular occasion, where the error is -7.7 nm at 21 nm from the beacon, the pilot executed a procedure turn downwind when the winds on that particular flight were 30 knots. As shown earlier in Table 5.9, there were three approaches that can account for the large error quantities in the angular FTE column. These occurred at the one, two, and three nautical mile points.

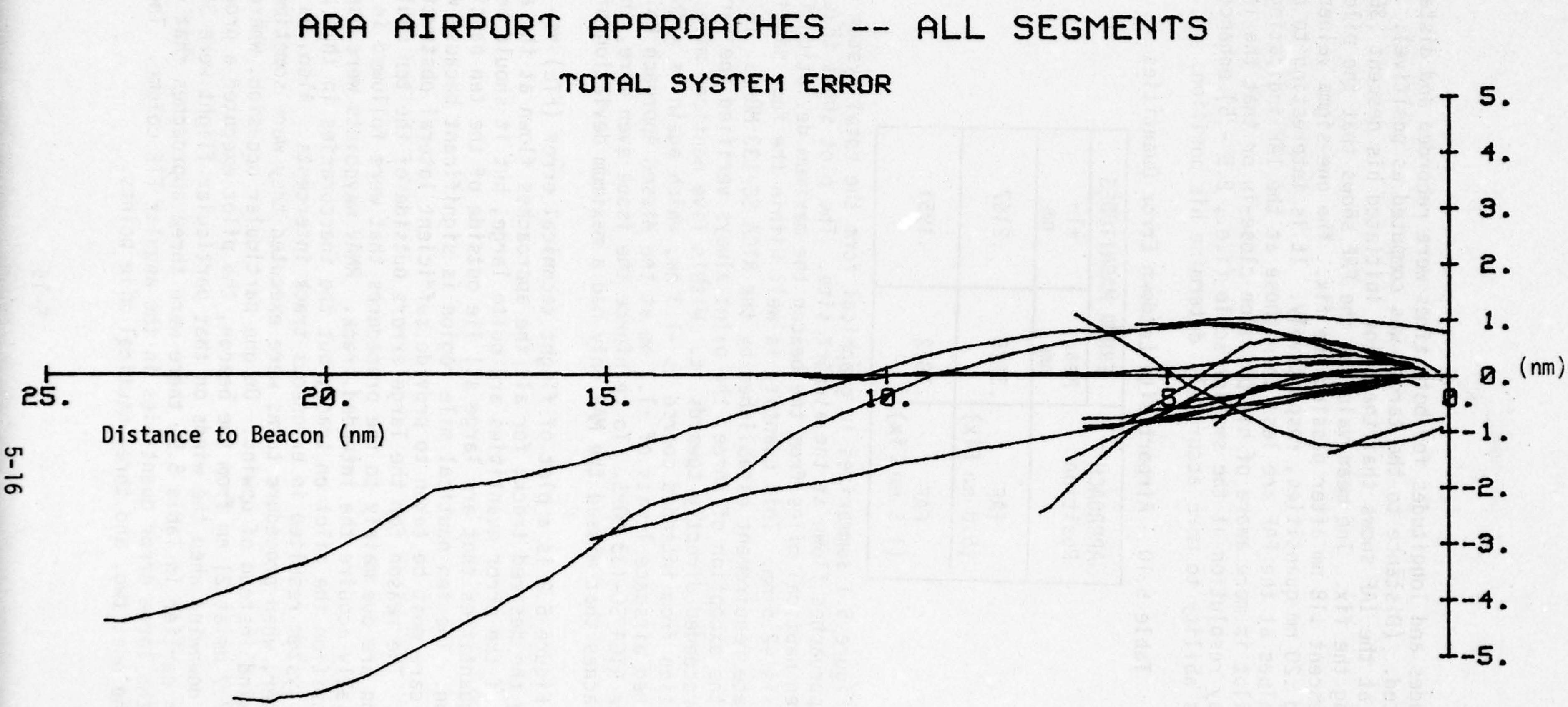


Figure 5.1 ARA Airport Single Beacon Approach Total System Cross Track Error

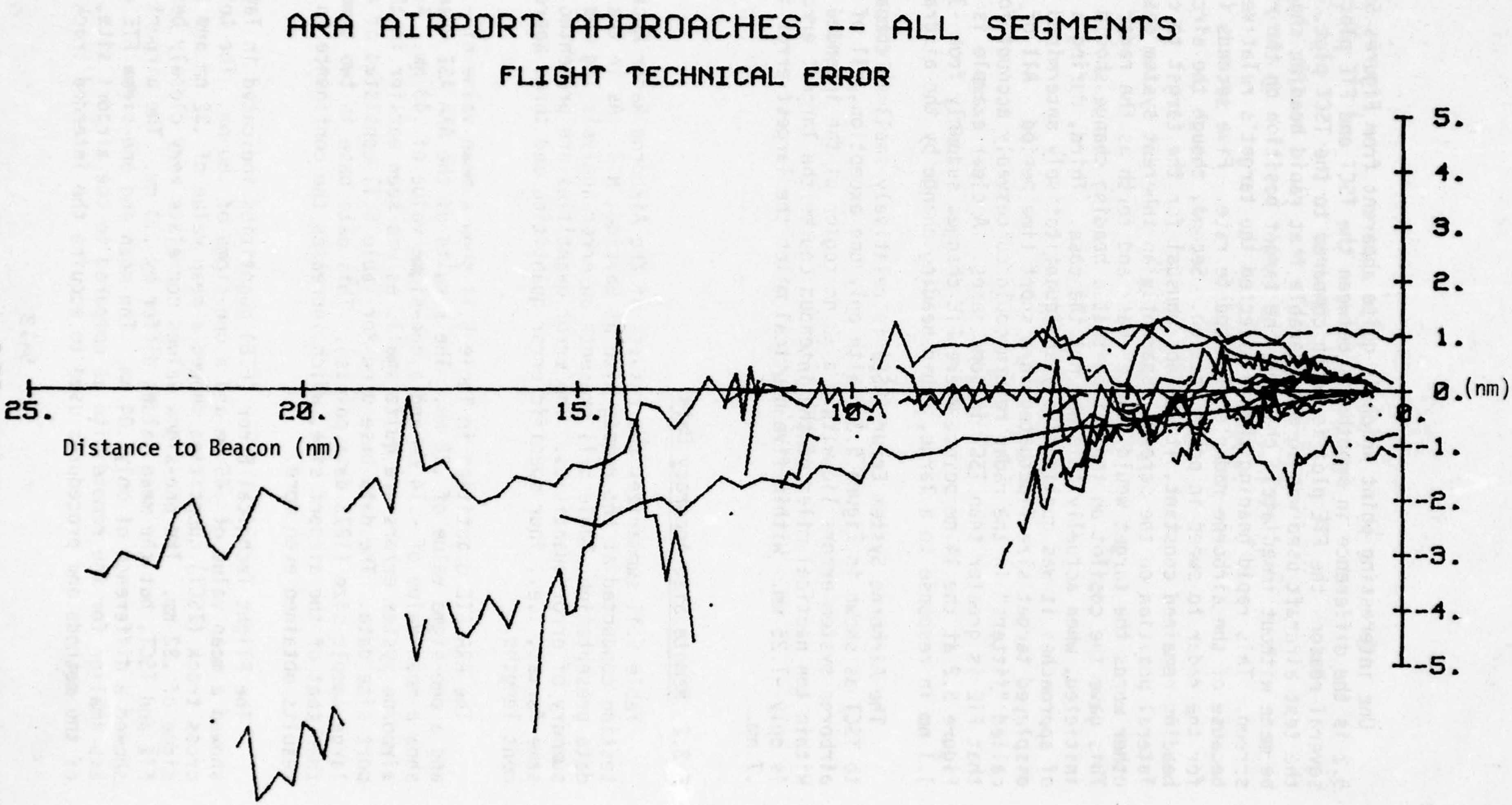


Figure 5.2 ARA Airport Single Beacon Approach Flight Technical Error

One interesting point which is quite apparent from Figures 5.1 and 5.2 is the difference in smoothness between the TSCT and FTE plots. For several reasons the FTE plot is rough compared to the TSCT plot. First, the the test aircraft used was so manueverable that rapid heading changes could be made without immediately changing the target position on the radar screen. This rapid heading change affected the target's relative position because of the airborne radar's slow update rate. Five seconds is required for the radar to sweep in one direction. Second, though the aircraft heading remained constant, it was not unusual for the target to change lateral position on the screen, apparently an inherent system design. In other words the target would "dance" back and forth as the radar sweeps. This gave the copilot an indication that a heading change should be initiated, when actually this was not the case. Third, during a number of approaches it was qualitatively and quantitatively determined that the displayed target size fluctuated in a short time period. All of these so-called "jitters" in the radar return could conceivably account for the fact that FTE is greater than TSCT in some cases. A clear example is shown in Figure 5.2 at the 14 nm point, where FTE changes suddenly from -3 nm to 1.1 nm in response to a large, rapid heading change by the aircraft.

The Airborne System Error (ASE) is relatively small in comparison to TSCT as shown in Figure 5.3. With only one exception, all of the airborne system errors lie within a ±2 nm region of the intended course. Within ten nautical miles of the intended course the largest error seen is only -1.25 nm. Within five nautical miles the largest error is only .7 nm.

5.3.2 Remote Site Accuracy Data

Table 5.11 summarizes the results of the Airborne Radar Approach testing conducted at the remote site at Bayside, N.J. As in the airport data presentation, Table 5.11 presents an error analysis log and statistical summary of error quantities. The error quantities are presented in the same format, i.e., four specific error quantities and three approach segment lengths.

The ARA ATE quantities in Table 5.11 show a mean value of -.06 nm and a one-sigma value of .22 nm. The results of the ARA ASE quantities show a mean value of -.14 nm and a one-sigma value of .43 nm. Again the airborne system errors are quite small, as was seen earlier in the airport site data. The data base used for Table 5.11 consisted of a very large sample size (1273 data points). This data base is two times larger than that of the airport site, which increases the confidence in the results obtained even more.

The Flight Technical Error (FTE) quantities indicated in Table 5.11 showed a mean value of .45 nm and a one-sigma of .80 nm. The total system cross track (TSCT) quantities showed a mean value of .32 nm and a one-sigma of .82 nm. The one-sigma values correlate very closely between FTE and TSCT, but the mean values differ by .13 nm. The airport data showed a difference of only .04 nm. The mean and one-sigma FTE quantities are smaller for the remote site as compared to the airport site, because of the methods and procedures used to acquire the intended track. When

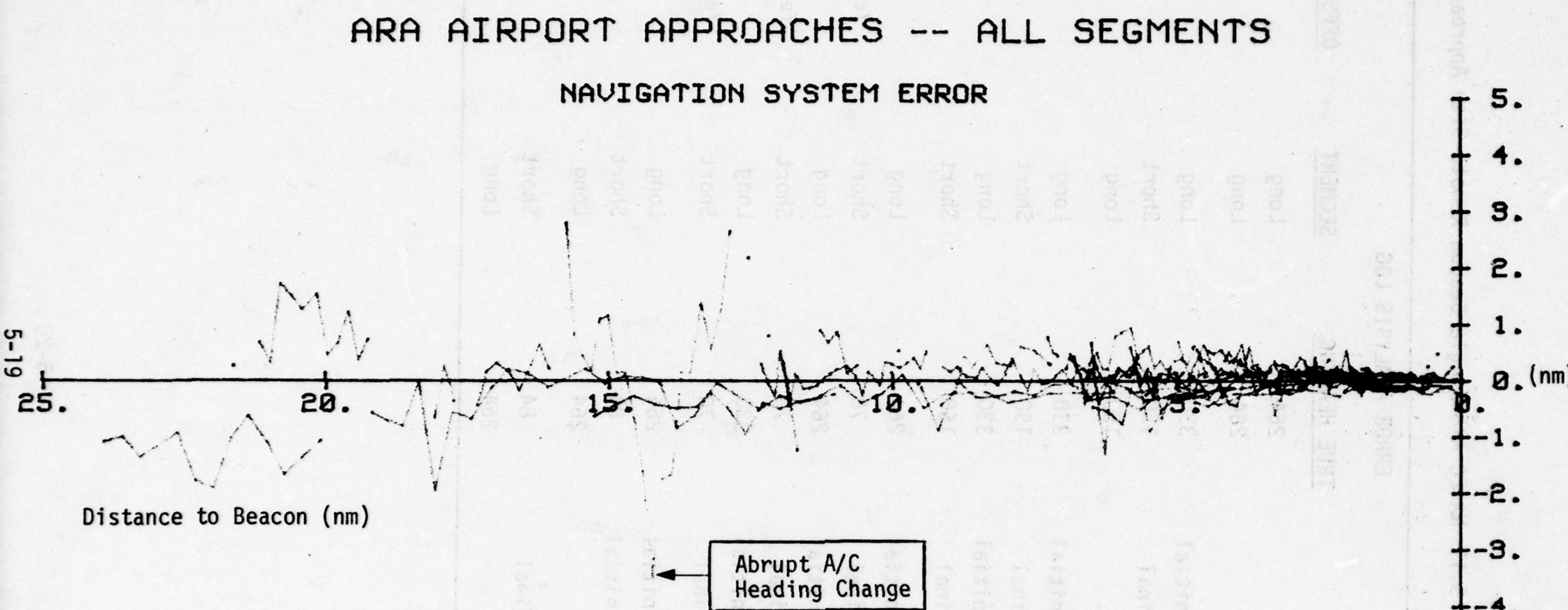


Figure 5.3 ARA Airport Single Beacon Approach Airborne System Error

Table 5.11 NAFEC ARA Single Beacon Remote Site Approach

ERROR ANALYSIS LOG

IDENTIFIER	TRUE HEADING	SEGMENT	OFFSET
11/14/78 -1	264	Long	
11/14/78 -2	264	Long	
11/15/78 -3 Initial	330	Long	
11/15/78 -3 Final	150	Short	
11/15/78 -4	150	Long	
11/20/78 -1 Initial	330	Long	
11/20/78 -1 Final	150	Short	
11/20/78 -2 Initial	330	Long	
11/20/78 -2 Final	150	Short	
11/29/78 -1 Initial	264	Long	
11/29/78 -1 Final	70	Short	Yes
11/29/78 -2 Initial	264	Long	
11/29/78 -2 Final	70	Short	Yes
11/29/78 -3 Initial	330	Long	
11/29/78 -3 Final	70	Short	Yes
12/01/78 -1 Initial	264	Long	
12/01/78 -1 Initial	84	Short	
12/01/78 -2	264	Long	
12/12/78 -1 Final	84	Short	
12/12/78 -2	264	Long	

Tabel 5.11 NAFEC ARA Single Beacon Remote Site Approach (Continued)

STATISTICAL SUMMARY

	$\overline{X}$(nm)	σ (nm)	DATA POINTS	APPROACHES SEGMENTS
ARA ATE				
LONG	-.1322	.1744	931	12
SHORT	.0854	.2278	198	5
OFFSET	.2316	.0942	144	3
TOTAL	-.0572	.2191	1273	20
ARA ASE				
LONG	-.1956	.4130	931	12
SHORT	-.1651	.4716	198	5
OFFSET	.2715	.2160	144	3
TOTAL	-.1380	.4312	1273	20
FTE				
LONG	.4880	.8339	931	12
SHORT	.3944	.7735	198	5
OFFSET	.3238	.5375	144	3
TOTAL	.4549	.7980	1273	20
TSCT				
LONG	.2924	.8414	931	12
SHORT	.2293	.8684	198	5
OFFSET	.5953	.4246	144	3
TOTAL	.3168	.8156	1273	20

flying in the airport area it was necessary before the initial approach to fly out twenty-five nautical miles to acquire the Initial Approach Fix. This resulted in the pilot executing a 180 degree procedure turn, therefore positioning the aircraft two to three miles north or south of the desired course. At the remote site though, this was not the case. When the aircraft left NAFEC to acquire the initial approach fix, no procedure turns were required, because the pilot could fly directly to the fix. The initial positioning of the aircraft in relation to the desired course resulted in both large FTE and TSCT quantities, especially at the airport site.

Table 5.12 presents the statistical error quantities, aggregated at one nautical mile intervals, for the Airborne Radar Approach test data collected at the remote site. The error quantities are presented in both linear and angular terms. Starting at 5 nm from the target the angular FTE quantities became quite large. Similar magnitudes of numbers were seen starting at 4 nm in the airport data. At one nautical mile the FTE mean is 11.2 degrees and the one-sigma is 16.88 degrees. The large one-sigma value, as in the airport data, can be attributed to the fact that on three occasions the pilot missed the target by .6 nm. As was the case many other times, the larger angular FTE and TSCT values within five nautical miles indicates the pilot's tendency to home to the station instead of flying the intended course. The linear values indicated in Table 5.12 are small and compare closely with the values obtained at the airport site. For example the airport data showed a large TSCT one-sigma of 1.3 nm at seven nautical miles, where the remote site data shows large TSCT one-sigma values of 1.2 and 1.3 nm at the eight and nine nautical mile points, respectively. These values are more easily seen in Figure 5.4, which is a plot of total system error.

Figure 5.4 represents in graphical form the total system error of all the approaches flown at the remote site. This plot verifies several points made earlier in this subsection. First, long approaches (greater than or equal to 10 nm) show a maximum deviation from intended track of -1.9 nm. This value of -1.9 nm, compared to a maximum deviation of -6.0 nm indicated in Figure 5.1, supports the statement that the procedures followed to acquire the initial approach course at the remote site were greatly improved. Within ten nautical miles Figure 5.4 indicates a maximum deviation from course of -3.3 nm. This value is still within the primary airspace requirements of ±4.0 nm established by RTCA SC-133. In addition to this one approach that starts out -3.3 nm off course, there are four other approaches that indicated a significant deviation from intended course.

Figure 5.5 is a plot of Flight Technical Error (FTE) vs. Along Track Distance to the target. The values indicated on the plot show a maximum value of -3.8 nm at nine nautical miles. This value is due to a large heading change. The heading change and the resulting jump in FTE is more clearly visible in Figure 5.6, which shows a plot of TSCT and FTE for an individual flight flown on 12 December 1978. The remaining values are quite good, with most values never exceeding ±2.5 nm.

Table 5.12 ARA Remote Site Single Beacon Approach Data Aggregated at One Nautical Mile Intervals

		LINEAR ERRORS				ANGULAR ERRORS			
NM	PTS	ATE	TSCT	FTE	ASE	TSCT	FTE	ASE	
1	15	.0810	.2142	.1983	.0159	12.0912	11.2155	.9129	MEAN
		.2312	.3064	.3034	.2858	17.0356	16.8767	15.9509	STD
2	20	-.0063	.1842	.2479	-.0637	5.2615	7.0660	-1.8251	MEAN
		.2162	.4961	.4580	.2926	13.9302	12.8972	8.3231	STD
3	20	-.0963	.2735	.3692	-.0957	5.2089	7.0166	-1.8279	MEAN
		.2119	.6320	.6208	.2834	11.8958	11.6906	5.3956	STD
4	20	-.0365	.4062	.5149	-.1087	5.7988	7.3350	-1.5563	MEAN
		.2029	.8040	.7803	.3117	11.3653	11.0384	4.4561	STD
5	20	-.0342	.5091	.6216	-.1126	5.8134	7.0870	-1.2897	MEAN
		.2125	.9194	.8523	.3316	10.4193	9.6731	3.7946	STD
6	15	-.0926	.2963	.5772	-.2809	2.8271	5.4945	-2.6800	MEAN
		.1797	.8957	.8580	.3188	8.4907	8.1379	3.0412	STD
7	12	-.1133	.3863	.6771	-.2909	3.1584	5.5252	-2.3794	MEAN
		.1616	.9579	.9935	.4214	7.7920	8.0781	3.4452	STD
8	12	-.1080	.3649	.6019	-.2369	2.6119	4.3023	-1.6962	MEAN
		.1636	1.1196	1.1490	.4720	7.9670	8.1731	3.3765	STD
9	12	-.1364	.3874	.6360	-.2486	2.4646	4.0424	-1.5825	MEAN
		.1778	1.2640	1.2744	.3427	7.9946	8.0594	2.1805	STD
10	8	-.1408	.2061	.5175	-.3114	1.1807	2.9623	-1.7835	MEAN
		.1729	.9315	.6994	.3578	5.3217	4.0006	2.0492	STD

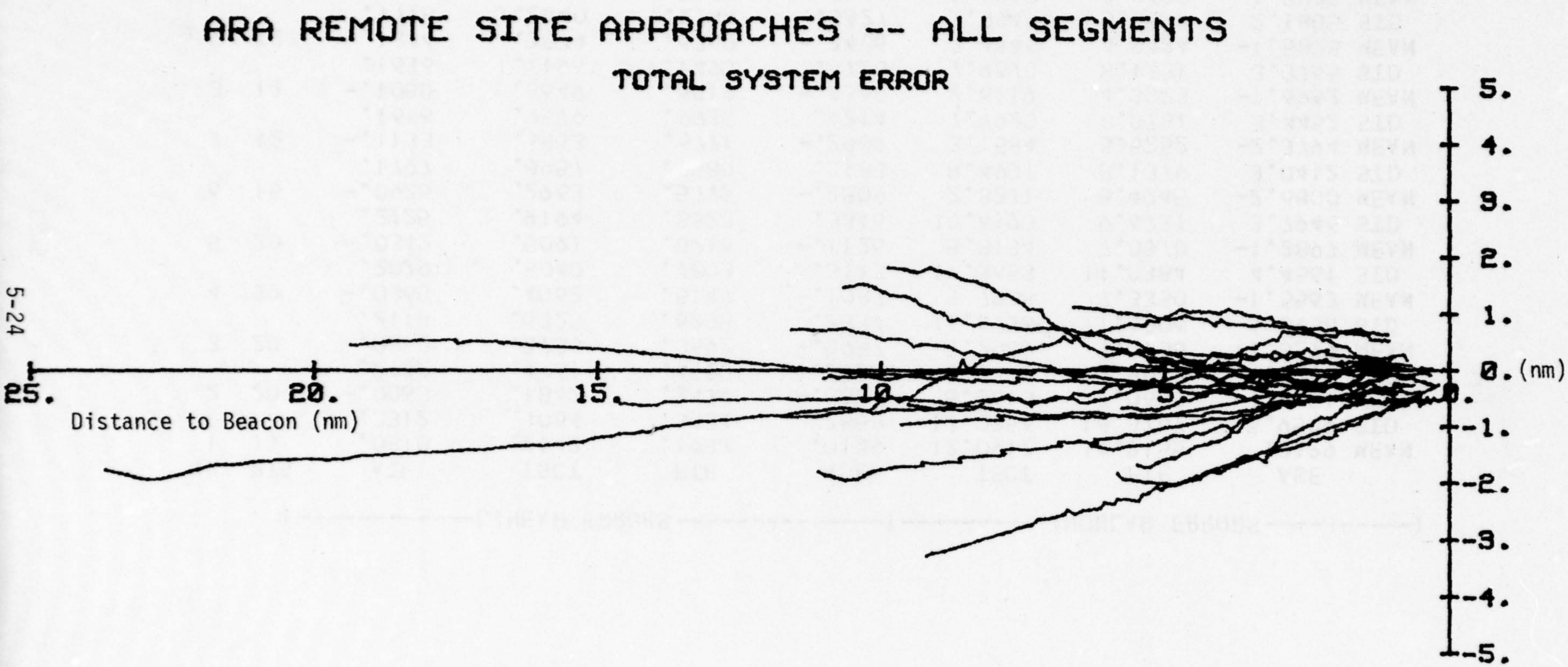


Figure 5.4 ARA Remote Site Single Beacon Approach Total System Cross Track Error

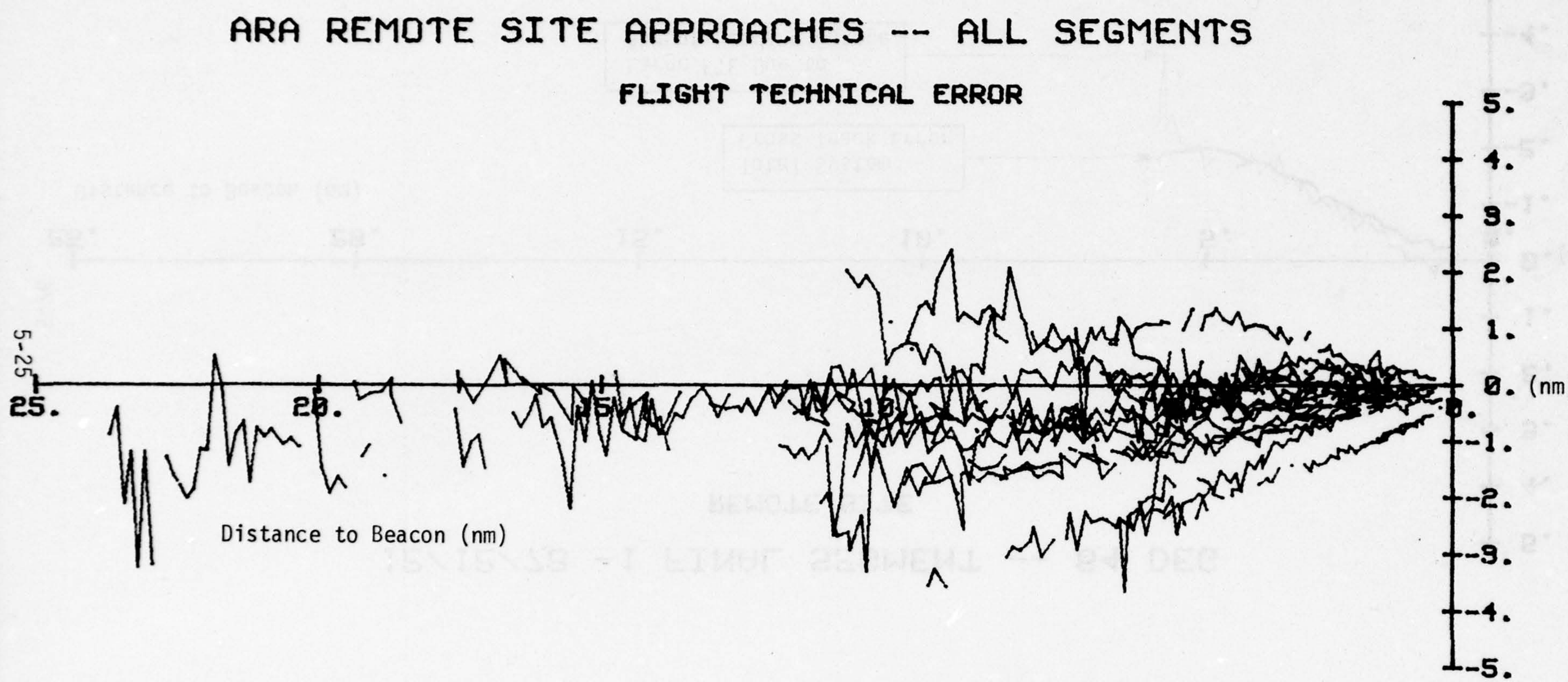


Figure 5.5 ARA Remote Site Single Beacon Approach Flight Technical Error

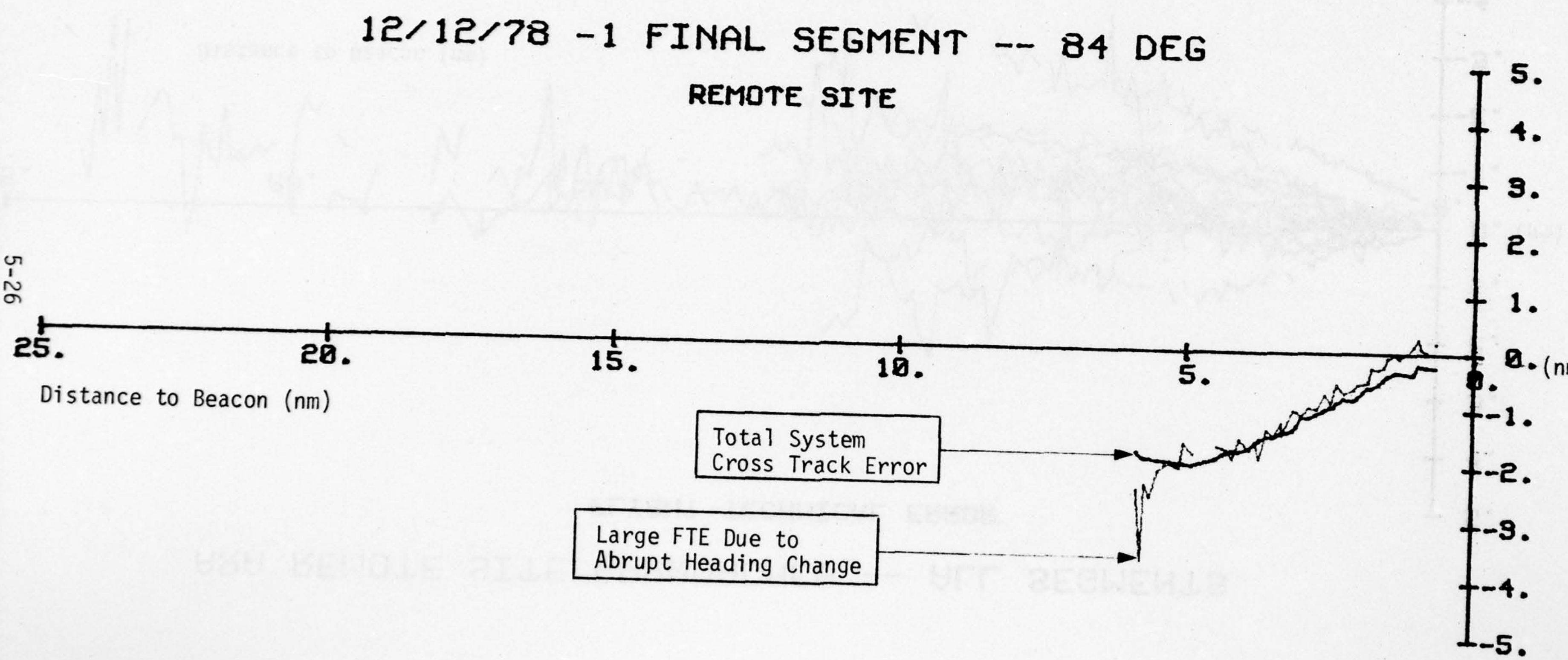


Figure 5.6 ARA Remote Site TSCT and FTE Plot: Final Segment of an Approach Flown, 12 December 1978

Figure 5.7 is a graphical representation of the remote site Airborne System Error (ASE). All of the errors shown in Figure 5.7 lie within a ±2 nm region with the exception of two points. At twelve nautical miles Figure 5.7 shows an airborne system error of 2.6 nm, while at the twenty-two nautical mile point a value of -2.2 nm is indicated. All of the errors within the five mile region are quite low, never exceeding 1.1 nm. The Airborne System Error at both the remote and airport sites is very small, which indicates the airborne radar is reliable and offers good repeatability.

5.3.3 Offshore Site Accuracy Data

Table 5.13 summarizes the results of the Airborne Radar Approach testing conducted at the offshore site. The offshore site utilized Brandywine Lighthouse, located in the Delaware Bay, as the location to place the beacon. The beacon was situated in such a manner so as to place it approximately thirty feet above the water's surface. Table 5.13 consists of an error analysis log and statistical summary of error quantities. This table is similar to the ones presented in Sections 5.3.1 and 5.3.2, and summarizes the mean values, standard deviations and the number of data points in four specific areas.

Table 5.13 indicates a mean ARA ATE quantity of -.001 nm and a one sigma of .24 nm. The results of the ARA ASE quantities shows a mean value of -.22 nm and a one sigma value of .52 nm. The Airborne System Errors once more are small. At the offshore site the ARA ATE mean is virtually zero, with the same holding true for the remote sites. The airport site ATE is larger, but is still a comparatively small value. These data were calculated from a sample size of 1219 data points. This sample size lends itself to a very high confidence level.

The Flight Technical Error (FTE) and Total System Cross Track (TSCT) quantities indicated in Table 5.13 correlate to the quantities previously seen in the airport and remote site data with one exception. The FTE quantities in Table 5.13 showed a mean value of -.07 nm and a one sigma of 1.03 nm. The TSCT quantities indicated show a mean value of -.30 nm and a one sigma of .92 nm. Again the one sigma values are similar in magnitude, but the mean value at the offshore site is much smaller than at the airport or remote sites. The one sigma values for FTE and TSCT closely correlate, but the mean value difference at the offshore site is much smaller. The offshore site data showed a difference of -.22 nm. The FTE values on some approaches are similar in magnitude to the TSCT values, this indicates that the pilot flew a course other than the one specified on the approach plate. Also, as mentioned in Section 5.3.2, the procedure turn executed to acquire the intended track had a considerable impact on track keeping.

Table 5.14 summarizes in statistical quantities the Airborne Radar Approach test data collected at the offshore site. This data summary consists of error quantities aggregated at one nautical mile intervals, starting at ten nautical miles from the target. As in Sections 5.3.1 and 5.3.2, these quantities were calculated in both linear and angular

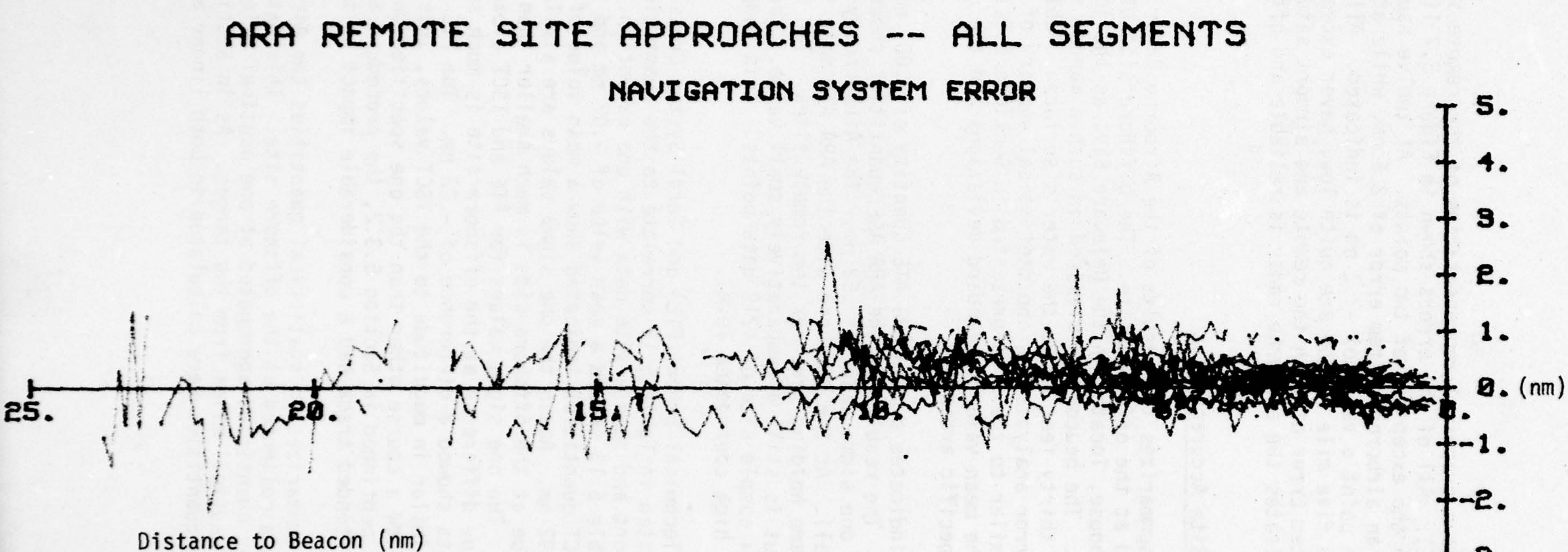


Figure 5.7 ARA Remote Site Single Beacon Approach Airborne System Error

Table 5.13 NAFEC ARA Single Beacon Offshore Site Approach

STATISTICAL SUMMARY

	$\overline{X}$(nm)	σ(nm)	DATA POINTS	APPROACH SEGMENTS
ARA ATE				
LONG	.0052	.2502	978	9
SHORT	-.0115	.1014	123	3
OFFSET	-.0449	.2697	118	2
TOTAL	-.0013	.2418	1219	14
ARA ASE				
LONG	-.2235	.5588	978	9
SHORT	-.0315	.2235	123	3
OFFSET	-.3522	.2678	118	2
TOTAL	-.2166	.5173	1219	14
FTE				
LONG	-.0844	1.0456	978	9
SHORT	.4269	.6026	123	3
OFFSET	-.5054	1.0604	118	2
TOTAL	-.0736	1.0319	1219	14
TSCT				
LONG	-.3079	.8938	978	9
SHORT	.3954	.5081	123	3
OFFSET	-.8575	1.0230	118	2
TOTAL	-.2901	.9198	1219	14

ERROR ANALYSIS LOG

IDENTIFIER	TRUE HEADING	SEGMENT	OFFSET
11/14/78 -3 Initial	150	Long	
11/14/78 -3 Final	300	Short	Yes
11/15/78 -1	222	Long	
11/15/78 -2	222	Long	
12/12/78 -3	150	Long	
12/12/78 -4 Initial	150	Long	
12/12/78 -4 Final	330	Short	
12/13/78 AM-1 Initial	222	Long	
12/13/78 AM-1 Final	42	Short	
12/13/78 AM-2 Initial	222	Long	
12/13/78 AM-2 Final	42	Short	
12/13/78 AM-3 Initial	150	Long	
12/13/78 AM-3 Final	190	Short	Yes
12/14/78 -1	222	Long	

Table 5.14 ARA Offshore Site Single Beacon Approach Data Aggregated At One Nautical Mile Intervals

		I------------LINEAR ERRORS			------------I------------	ANGULAR ERRORS------------I		
NM	PTS	ATE	TSCT	FTE	ASE	TSCT	FTE	ASE	
1	12	.1006	-.0971	-.0574	-.0396	-5.5453	-3.2875	-2.2704	MEAN
		.1585	.3415	.2775	.1594	18.8527	15.5117	9.0594	STD
2	13	.0304	-.1115	-.0194	-.0921	-3.1910	-.5557	-2.6368	MEAN
		.1929	.5694	.5285	.1490	15.8904	14.8013	4.2612	STD
3	14	.0612	-.2180	-.0135	-.2046	-4.1569	-.2571	-3.9010	MEAN
		.1684	.7842	.7578	.1947	14.6493	14.1758	3.7140	STD
4	13	.0416	-.3929	-.1991	-.1938	-5.6103	-2.8500	-2.7738	MEAN
		.2376	.9262	.8715	.2032	13.0373	12.2908	2.9088	STD
5	13	.0707	-.4680	-.2968	-.1712	-5.3472	-3.3971	-1.9610	MEAN
		.1761	1.1303	1.0917	.2172	12.7387	12.3162	2.4875	STD
6	11	.0635	-.3011	-.2013	-.0998	-2.8725	-1.9215	-.9527	MEAN
		.1484	.9764	.8876	.2504	9.2432	8.4150	2.3894	STD
7	9	.0807	-.4989	-.3280	-.1709	-4.0768	-2.6826	-1.3989	MEAN
		.1239	1.0843	1.0472	.3094	8.8048	8.5082	2.5310	STD
8	9	.0599	-.5067	-.1725	-.3342	-3.6241	-1.2355	-2.3918	MEAN
		.0882	1.2288	1.2464	.2357	8.7327	8.8552	1.6876	STD
9	9	.0734	-.5599	-.5063	-.0537	-3.5599	-3.2195	-.3416	MEAN
		.1355	1.3786	1.3326	.3192	8.7085	8.4222	2.0312	STD
10	9	.0917	-.5293	-.2671	-.2621	-3.0296	-1.5301	-1.5015	MEAN
		.2727	1.4938	1.7479	.4524	8.4960	9.9148	2.5900	STD

terms. As seen in the remote site data, the offshore data in Table 5.14 shows large FTE angular quantities starting at five nautical miles. At one nautical mile the FTE angular quantities show a mean value of -3.29 degrees and a one-sigma of 15.51 degrees. At five nautical miles quantities of similar magnitude are seen, a mean value of -3.40 degrees and a one-sigma of 12.31 degrees. The angular TSCT quantities correlate closely to the FTE quantities. At one nautical mile the angular TSCT shows a mean value of -5.55 degrees and a one-sigma of 18.85 degrees. The five mile point data for the TSCT quantities shows a mean value of -5.35 degrees and a one-sigma of 12.74 degrees.

The linear error quantities indicated in Table 5.14 show some large FTE and TSCT one-sigma values outside of five nautical miles. At the ten nautical mile point the FTE quantities show a mean value of -.27 nm and a one-sigma value of 1.75 nm. The TSCT values at the ten nautical point shows a mean value of -.53 nm and a one-sigma of 1.50 nm.

The linear Along Track Errors (ATE) presented in Table 5.14 show small values at all of the points indicated. The linear navigation system cross track values indicate small magnitudes, as do the ATE values. As seen in the tables presented earlier the small quantities show once more that the Airborne Radar System is, of itself, quite accurate. For example, at one nautical mile the linear ASE values indicate a mean value of -.04 nm and a one-sigma of .16 nm.

Figure 5.8 represents in graphical form the Total System Error of all the approaches flown at the offshore site. With the exception of two approaches, all of the others lie within a route width of ±2 nm. In general, the approaches flown at the offshore site were quite good. Even the two approaches that lie outside of the ±2 nm region still lie within the ±4 nm primary airspace requirements established by RTCA SC-133. It is not obvious exactly what caused these two tracks to be so far off of the intended course. It is assumed, though, that the pilots flew a course other than the one specified on the approach procedures.

Figure 5.9 is a plot of Flight Technical Error (FTE) vs. distance along the desired track. These data were collected for all of the approaches flown at the offshore site. These data show a maximum deviation from intended course of 4.5 nm. Other large deviations show a maximum value of 3.2 nm. As mentioned earlier it was assumed the large FTE quantity of 4.5 nm can be attributed to the pilot not flying the intended course specified on the approach procedures. This fact can be verified by looking at Figures 5.10 and 5.11. These figures are a graphical representation of both the TSCT and FTE quantities for two individual approaches. Both figures indicate that the aircraft was being flown with great precision on a course other than the one specified, but the plots still indicate the approaches were flown with reasonable precision.

Figure 5.12 is a graphical representation of the Airborne System Error (ASE), for the approaches flown at the offshore site. Outside of ten nautical miles Figure 5.12 shows a maximum Airborne System Error (ASE) of -3.2 nm. Between ten and five nautical miles the plot indicates a maximum error of 1.8 nm. Within five nautical miles the plot indicates a maximum

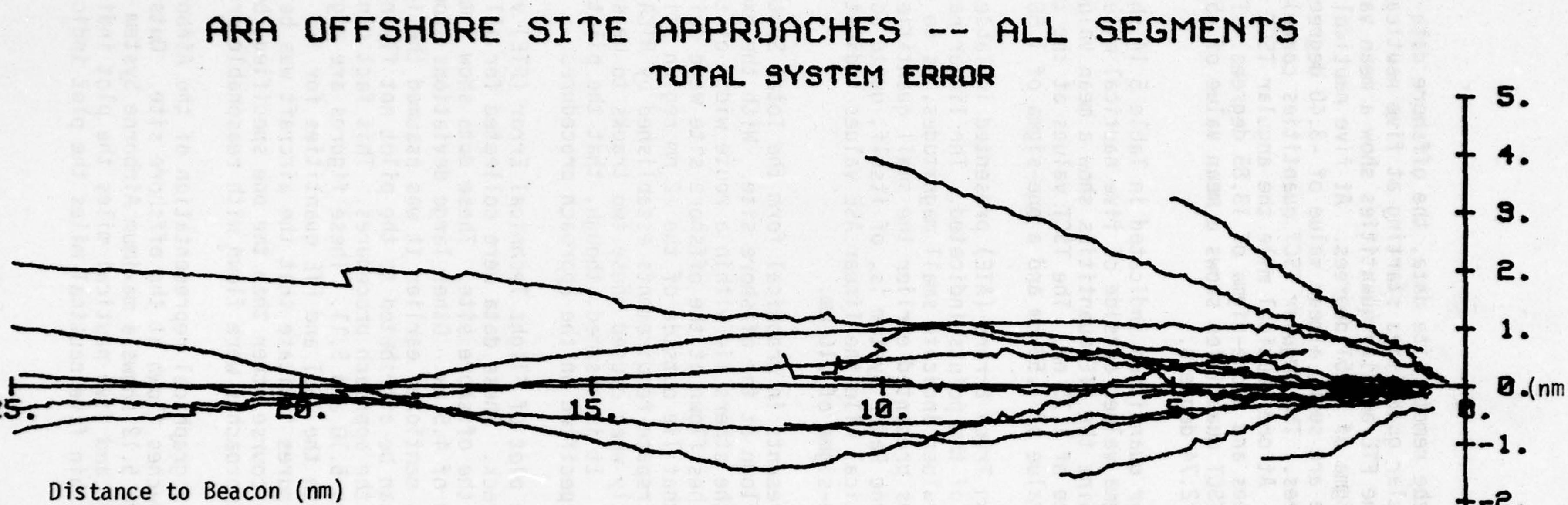


Figure 5.8 ARA Offshore Site Single Beacon Approach Total System Cross Track Error

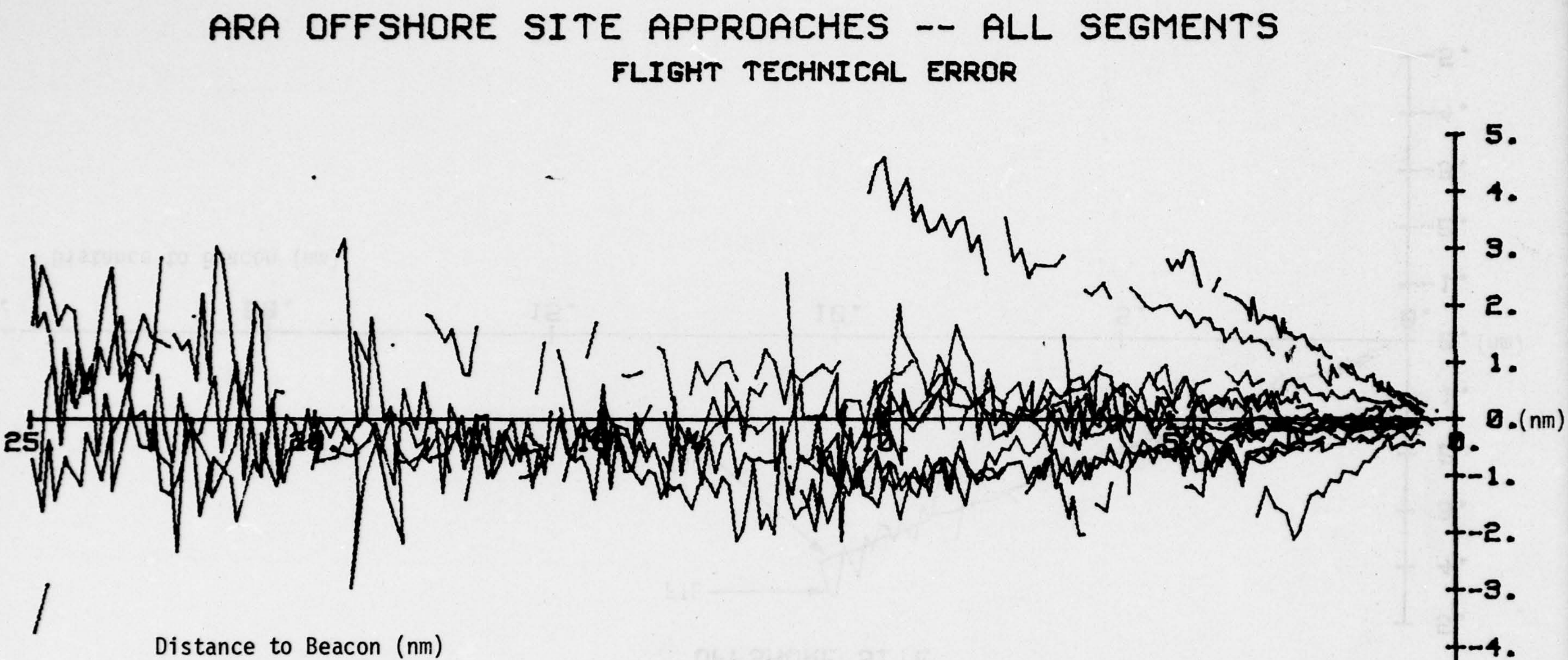


Figure 5.9 ARA Offshore Site Single Beacon Approach Flight Technical Error

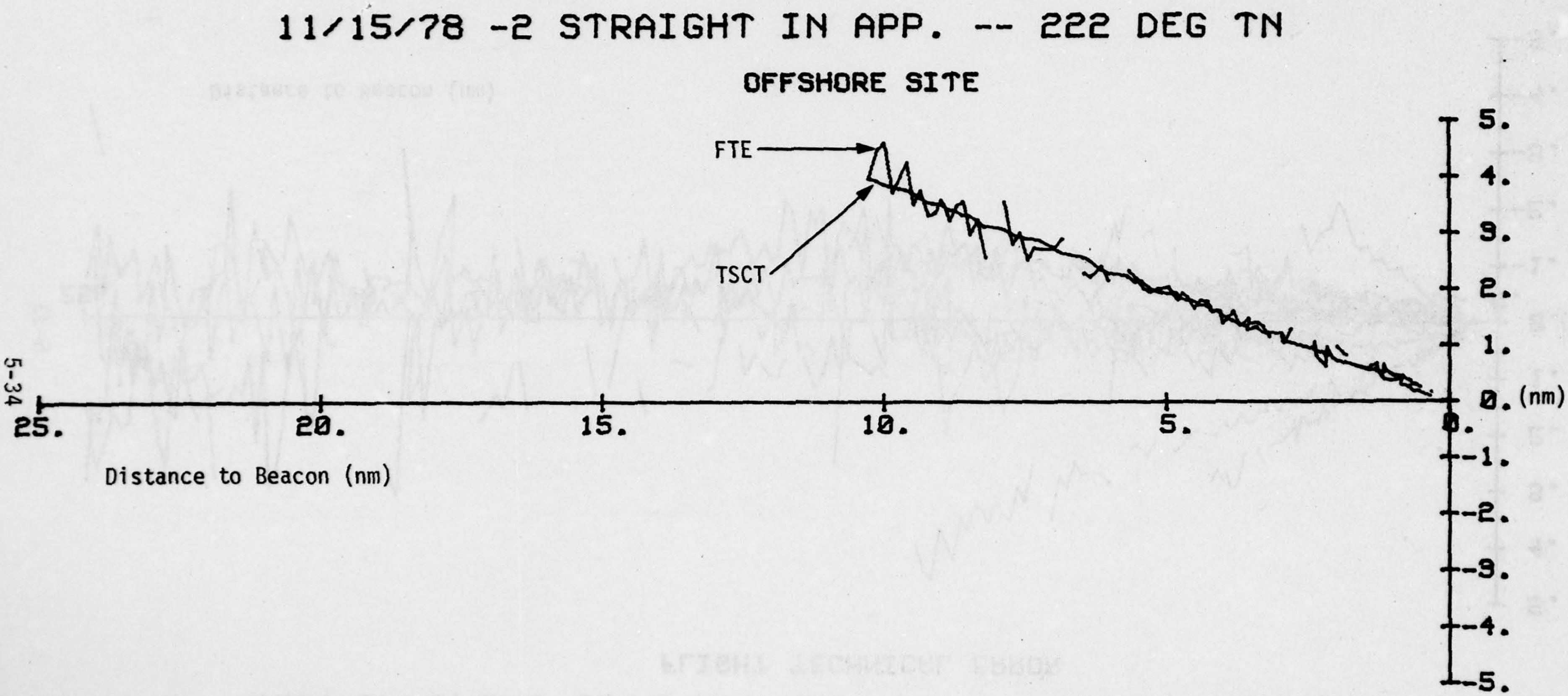


Figure 5.10 ARA Offshore Site TSCT and FTE Plot: Direct Straight Approach Flown on 15 November 1978

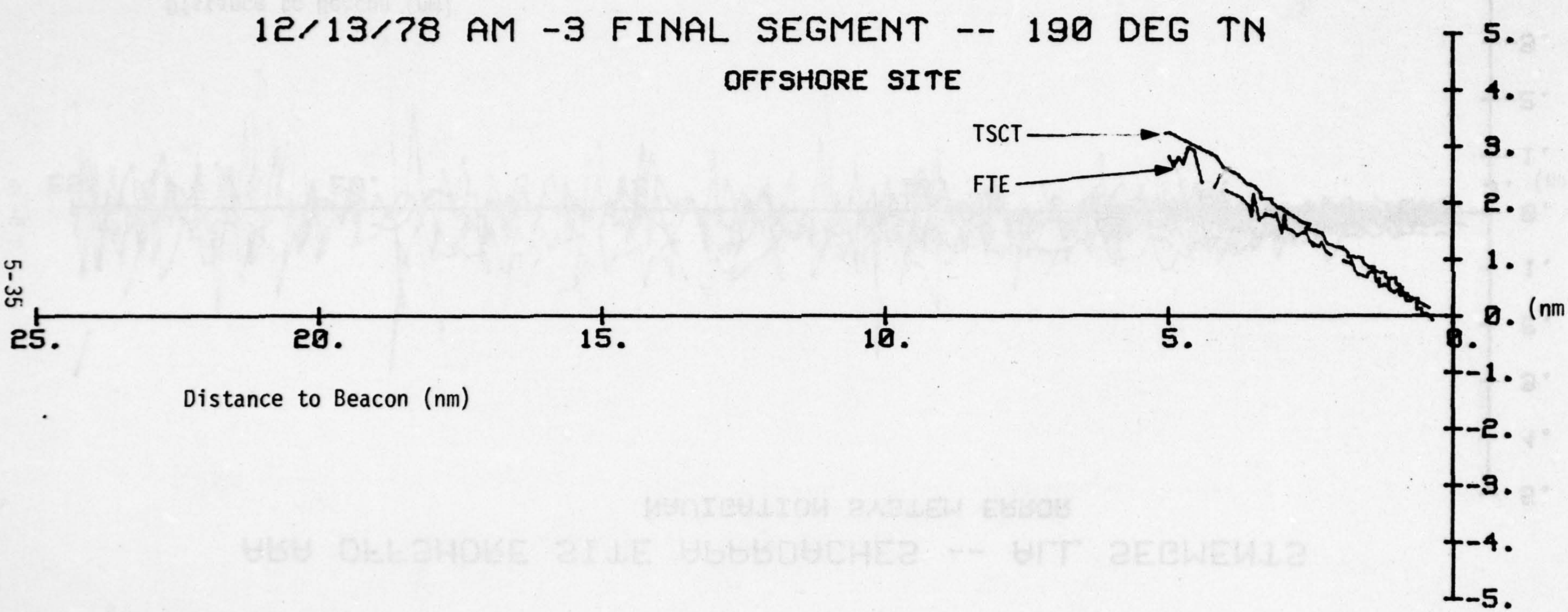


Figure 5.11 ARA Offshore Site TSCT and FTE Plot: Final Segment of an Approach Flown on 13 December 1978

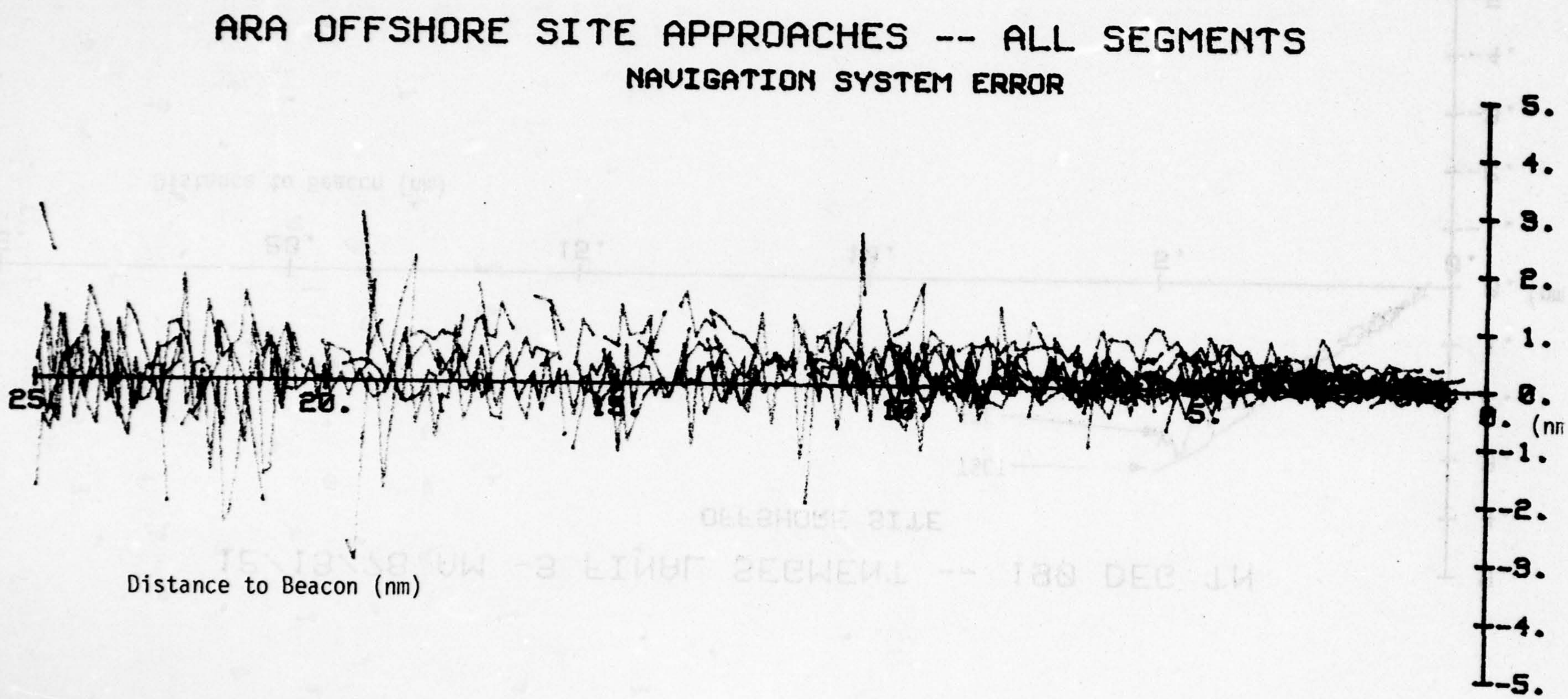


Figure 5.12 ARA Offshore Site Single Beacon Approach Airborne System Error

error of only 1.0 nm. These numbers are quite significant to offshore users. Obstruction clearance is just as critical to offshore sites such as oil rigs, both from other oil rigs or surface ships, as it is to land-side uses. Within a five mile zone the ASE quantities, at all of the sites tested, are reasonably consistent and small. This, along with the large data base acquired, assures a high confidence level in the ability of the airborne system to accurately guide the pilot to a predetermined target.

Some of the other error quantities discussed in this sub-section indicate several additional factors. First, the Total System Cross Track (TSCT) quantities within a five nautical mile region of the target are generally less than two nautical miles. This shows that both the system and the pilot working together display a reasonable ability to navigate to the target. There were a total of only six out of the thirty-five approaches flown that missed the target. But even these six, having a value no greater than .8 nm, were within the primary airspace requirement of ±1.7 nm established by RTCA SC-133. The Flight Technical Error (FTE) quantities shown indicated that possibly poor course acquisition procedures accounted for some large FTE values.

5.4 OPERATIONAL EVALUATION OF THE ARA CONCEPT

Operationally the Airborne Radar Approach (ARA) concept is a practical solution to navigation where conventional navigation aids are unavailable. There are certain areas though that need careful consideration which relate to the operational feasibility of the Airborne Radar Approach System. First, the ground based beacon transponders must insure an effective backup system. In Section 6.1, Table 6.2 shows that when the single beacon tests were conducted, often at times the beacons were either inoperative or weak and intermittent. Second, the airborne system needs to offer more advanced features to reduce the pilot's workload. The copilot must constantly monitor the gain, tilt, range controls and aircraft heading. To alleviate some of the crew member's workload more advanced Sensitivity Time Constant (STC) circuitry in the Airborne Radar System or variable-gain beacons are required. It should be noted that the Sensitivity Time Constant (STC) adjustment for this particular radar unit was <u>not</u> properly adjusted; this was verified by Bendix Corporation after the completion of the flight test program. Also, the pilot needs an indication of the aircraft's actual deviation from intended course. This will aid the pilot in flying the intended course more accurately. Third, as will be shown in Section 6.3, it is very important that the crew members receive formal training before attempting to fly a successful Airborne Radar Approach.

The Airborne System Error quantities presented in Section 5.3 indicate that the present "State-of-the-Art" system is capable of accurate navigation. The operational problems lie in two areas: pilot's workload and pilot's interpretation of the information presented. Certainly training and workload correlate closely together. If the pilot is trained well and understands the concepts involved in flying the approach, the workload is reduced. In lieu of this even a trained pilot should not have to constantly change display controls because this only distracts from his primary duty; to safely navigate the aircraft on a predetermined course to a

predetermined target. At present the airborne system is adequate, but many improvements could and should be made.

5.4.1 Landside ATC Integration

Landside ATC integration could offer some interesting problems because of the items discussed in Section 5.1.3. Although the airborne system accuracy is good, some difficulties exist in integrating Airborne Radar Approaches into the present ATC system. Comparatively speaking, a standard NDB approach is the present day non-precision approach that is most similar to an Airborne Radar Approach. Both the ILS and VOR approach aids offer an omnidirectional capability that neither the NDB nor ARA offers. As with any non-precision approach the pilot's proficiency will directly impact the overall accuracy of the approach.

As shown in Section 5.3, the figures indicate that a ±4 nm route width, as established by RTCA SC-133, will be required. If an Airborne Radar Approach to a helipad requires more airspace, then the controller will surely need to consider this fact when vectoring other aircraft in his area, because this will surely affect the controller's position in assuring safety to aircraft in this area. The impact of this could potentially be delays in terminal operations. Airborne Radar Approach procedures also need to offer sufficient obstacle clearance, depending on the overall accuracy of the system. If this is the case then ARA altitude minimums might possibly have to be raised above those of the present day non-precision approaches.

The procedures utilized for ARA should also consider that, when making an Airborne Radar Approach, positive navigation is only available when flying to the target. This positive navigation might also necessitate the use of beacons instead of depending strictly on skin paint. This could possibly require that some other navigational aid be used to initially acquire the intended inbound track. At NAFEC, during the test program RNAV was used for initial course acquisition. Results show that the inaccuracy of the RNAV system used offered some poor course acquisition techniques in the terminal area. This presents another problem to the controller. The controller must then consider that the pilot will be using two operationally different navigational aids to fly the approach, both having different accuracies and different procedures necessary to make the approach successful. The landside integration of Airborne Radar Approaches could present difficulties at first, but in time, when standard procedures are developed and airborne system features are improved, airborne radar could possibly become an integral part of our terminal navigation system.

5.4.1.1 Airport

The airport site is without question the most important area in which to consider the ATC integration impact. The airport environment could produce many traffic and obstacle hazards not found at the remote and offshore sites. In an environment such as this, many considerations must be recognized so that the procedures utilized offer the utmost safety.

A major consideration is the airspace required to repeatably fly an Airborne Radar Approach down to established minimums successfully.

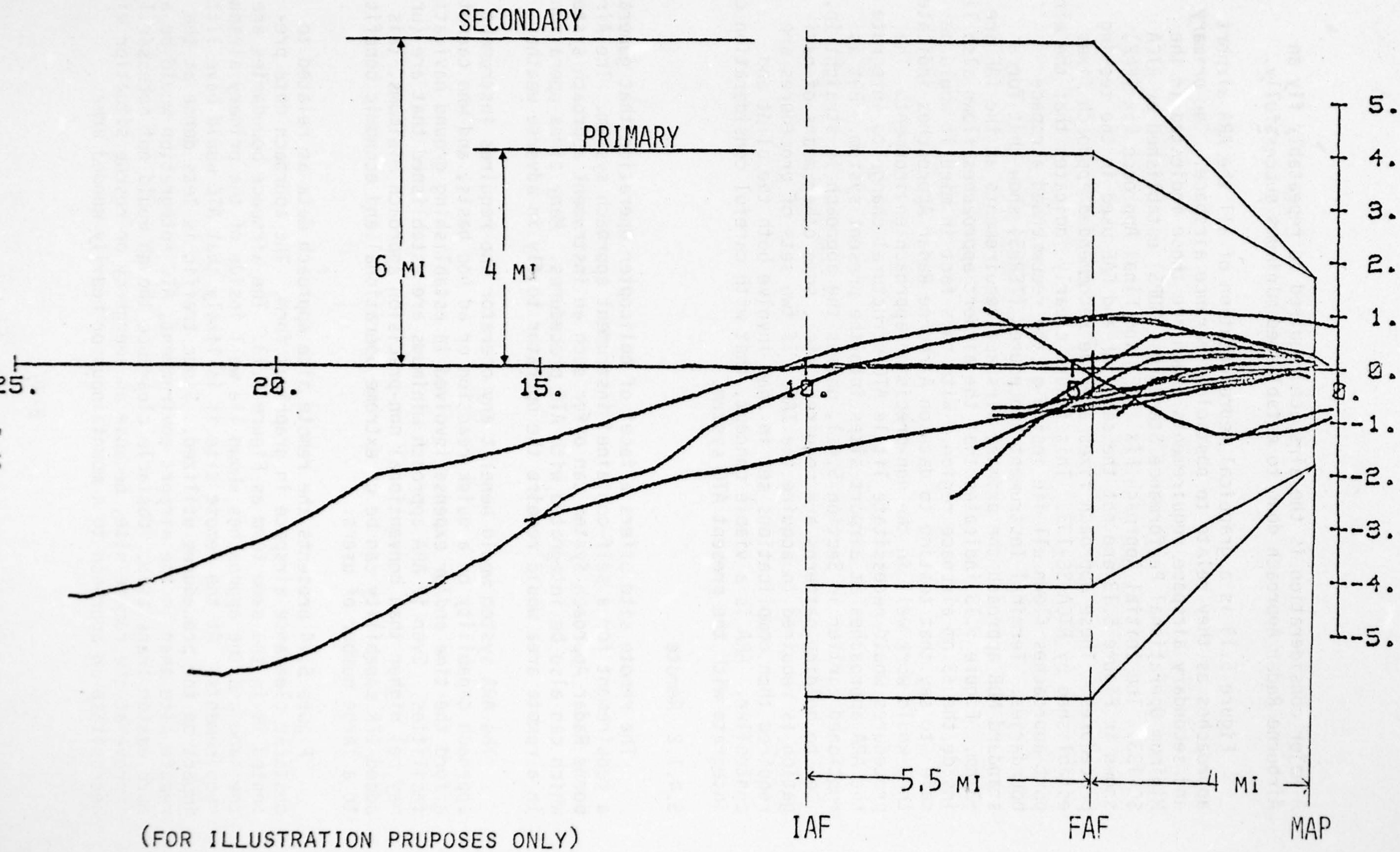
Figure 5.13 is a graphical representation of all the ARA airport approaches as they relate to obstacle clearance airspace. The primary and secondary airspace requirements shown are those indicated in the Minimum Operational Performance Standards (MOPS) established by RTCA SC-133. The Initial Approach Fix (IAF) and Final Approach Fix (FAF) shown in Figure 5.13 are not the same IAF and FAF used in the testing procedures. These approach fixes are the recommended approach fixes established by RTCA SC-133. This figure clearly indicates that the airport approaches flown all lie inside of the recommended airspace boundaries. Terminal Instrument Procedures (TERPS) show that for a standard NDB approach the primary airspace requirements at the IAF are ±3 nm. Figure 5.13 indicates that the airport approaches flown also lie inside the ±3 nm airspace region. With this fact in mind it would be safe to say that testing to date on Airborne Radar Approaches indicates they would work well in the non-precision approach environment. The procedures would necessitate little ATC structural change to integrate the ARA approaches at airport sites into the present system. But as mentioned earlier in Section 5.4.1, unless the approach is straight in, i.e. no holding patterns are required, etc., some other means of navigation is required to acquire the IAF. If two sets of procedures are required then complications set in that involve both the pilot and controller. ARA is a viable concept, that with careful consideration can integrate with the present ATC system.

5.4.1.2 Remote

The remote site offers a facet of helicopter operation that generates a requirement for a self-contained instrument approach system. The Airborne Radar Approach System can offer such an instrument approach system which can also be integrated with ATC procedures. Many times operation in a remote area would require the operator to fly in adverse weather.

The ARA system would benefit any operator who requires instrument approach capability on a quick reaction or ad hoc basis, and who cannot afford the time and/or expense involved in establishing ground navigation facilities. Even if ARA approach minimums are established that are (or may be) higher than conventional non-precision approach minimums, this added IFR capability can be of extreme operational and economic benefit to a large number of users.

Figure 5.14 presents the remote site approach data as related to obstacle clearance airspace in graphical form. The approach data presented is in the same form as Figure 5.13. The airspace boundaries are the same and the approaches shown lie well inside of the primary airspace requirements. At the remote site it is likely that ATC would have little impact on the procedures utilized. Since traffic is less dense at the remote site than in the airport environment, ATC integration would be a much easier transition. Obstacle clearance though would not necessarily improve at the remote site, because an emergency or rescue situation might necessitate an approach to a mountainous or heavily wooded area.



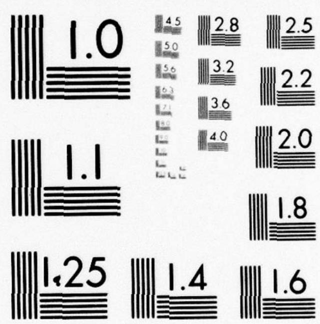
(FOR ILLUSTRATION PRUPOSES ONLY)

Figure 5.13 ARA Airport Approaches (all segments) Related to Obstacle Clearance Airspace

AD-A077 900 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7
AIRBORNE RADAR APPROACH SYSTEM FLIGHT TEST EXPERIMENT.(U)
OCT 79 L D KING, R J ADAMS DOT-FA79WA-4293
UNCLASSIFIED FAA/RD-79-99 NL

2 OF 2
ADA
077900

END
DATE
FILMED
2 -80
DDC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF

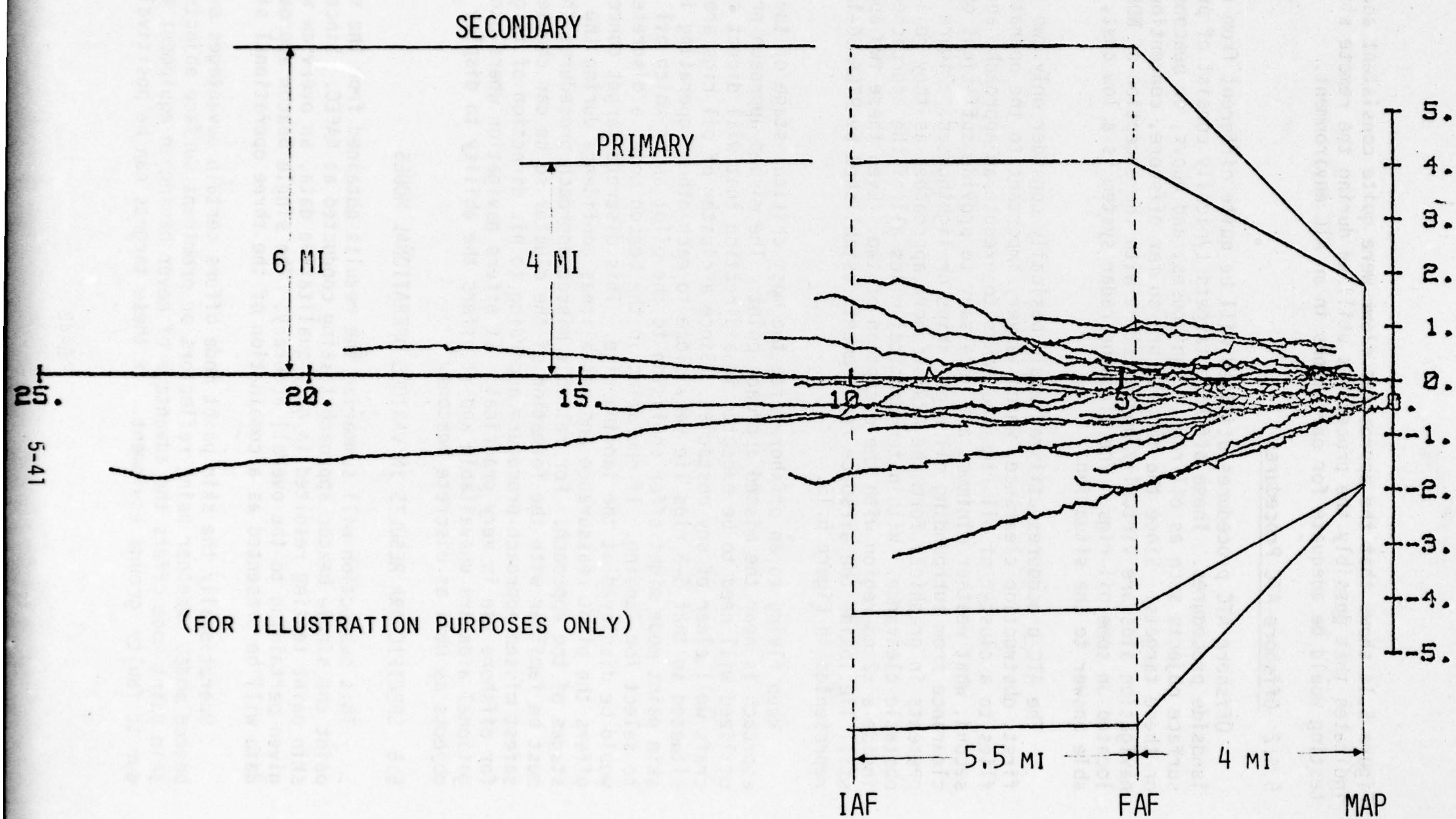


Figure 5.14 ARA Remote Site Approaches (all segments) Related to Obstacle Clearance Airspace

Figure 5.14 shows that the approaches flown were quite consistent and indicates that possibly the procedures utilized during the remote site testing would be adequate for operations in an ATC environment.

5.4.2 Offshore ATC Procedures

Offshore ATC procedures utilized will be quite different from the landside procedures. These offshore targets typically consist of prominent surface objects such as oil rigs, lighthouses, and buoys, or beacons placed on these targets. Since the targets are so far offshore, conventional navigation aids are virtually non-existent with the exception of NDB's located on some oil rigs. The airborne radar system is a low cost, dependable answer to the situation.

The ATC procedures utilized would basically consider only two items, first, obstruction clearance, which is very important to the operator who flies to a cluster of oil rigs and wants to execute an approach, and second, what weather minimums are necessary to provide sufficient obstacle clearance from surrounding oil rigs, ships or lighthouses. Figure 5.15 presents in graphical form the ARA offshore approaches as they relate to obstacle clearance. Within ten nautical miles all of the approaches lie inside a ±2 nm region with the exception of two. Even these two approaches still lie inside the airspace requirements established by RTCA SC-133 as represented in Figure 5.15.

When flying to an offshore site the most critical stage of the approach is near the missed approach point. The missed approach procedures utilized will need to be executed in a direction that will direct the aircraft well clear of any obstacles. Since a cluster of oil rigs are usually situated so that 6-8 rigs lie very close to each other, operating in the skin paint mode might offer confusion to the pilot as to which oil rig to select for landing. If operating in the beacon mode, a discrete return would be displayed at the landing site. This discrete target concept offers the pilot reassurance and establishes confidence during the final stages of the approach. For reliable missed approach procedures the pilot must be familiar with the formation of the cluster so he can choose the safest missed approach procedure according to his direction of flight. ARA for offshore use is very practical. It offers navigation where other navigational aids are unavailable and it offers the ability to display surface objects as well as discrete beacons.

5.5 SPECIFIC ARA RESULTS IN VARIOUS OPERATIONAL MODES

This subsection will summarize the results obtained from the skin paint and single beacon approach testing conducted at NAFEC. Since the skin paint testing resulted in only qualitative data, an overview will be given pertaining to the overall accuracy. The single beacon approach test data will be presented as a combination of the three operational sites.

Operationally the skin paint mode offers certain advantages over the beacon mode. Whether using reflectors or prominent surface objects, the skin paint mode offers the advantage of never having an equipment failure due to faulty ground equipment. If these targets can be positively

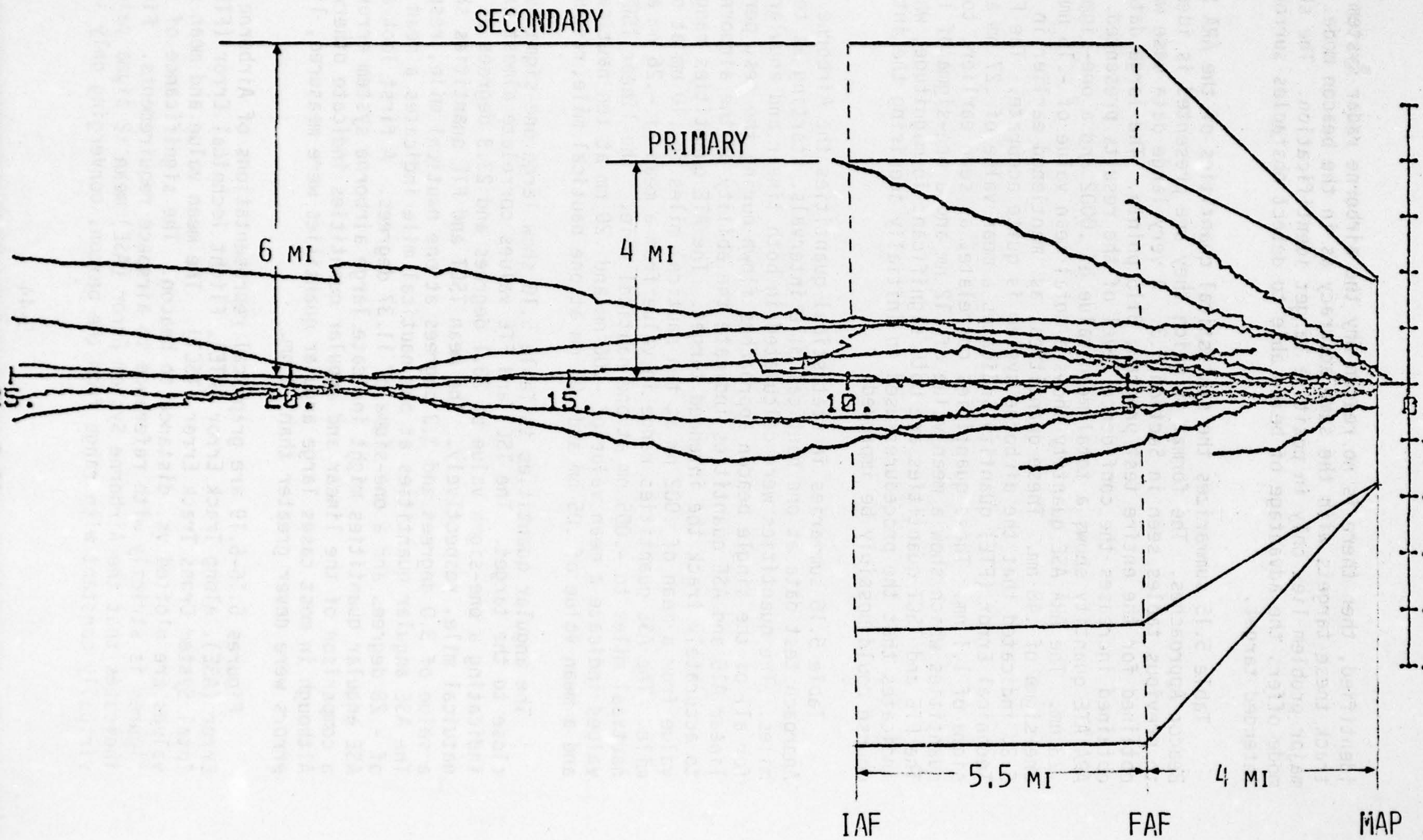


Figure 5.15 ARA Offshore Approaches (all segments) Related to Obstacle Clearance Airspace

identified, then there is no reason why the airborne radar system cannot track these targets with the same accuracy as in the beacon mode. The major problem lies only in positive target identification. The skin paint mode offers the advantage of being able to detect obstacles surrounding the intended target.

Table 5.15 summarizes the statistical quantities of the ARA Single Beacon Approaches. The format in which they are presented is identical to previous tables seen in Section 5.3. A very large data base was obtained for the entire test program, 3115 points. The large data base obtained increases the confidence level of the results presented. The ARA ATE quantity shows a total mean value of .0002 and a one-sigma of .23 nm. The ARA ASE quantity shows a total mean value of -.15 nm and a one-sigma of .48 nm. These quantities, as mentioned earlier in Section 5.3, indicated that the airborne system is quite accurate. The Flight Technical Error (FTE) quantity indicates a mean value of .27 nm and a one-sigma of 1.1 nm. These quantities correlate, as seen earlier, to the TSCT quantities which show a mean value of .12 nm and a one-sigma of 1.03 nm. The FTE and TSCT quantities are both significant in magnitude, which again indicates that the procedures used in initially acquiring the intended course could possibly be improved.

Table 5.16 summaries in statistical quantities the Airborne Radar Approach test data at one nautical mile intervals, starting at ten nautical miles. The quantities were calculated in both linear and angular terms for all of the single beacon approaches flown during the test period. The linear ATE and ASE quantities indicate the ability of the airborne system to accurately track the intended target. The ATE quantities range in value from a mean of .002 nm at ten nautical miles to .10 nm at one nautical mile. The ASE quantities range in value from a mean of -.26 nm at ten nautical miles to -.005 nm at one nautical mile. The linear TSCT and FTE values indicate a mean value of -.06 nm and .20 nm at ten nautical miles and a mean value of .05 nm and .06 nm at one nautical mile, respectively.

The angular quantities in Table 5.16 show large one-sigma quantities close to the target. The TSCT and FTE values correlate almost exactly, indicating a one-sigma value of 23.1 degrees and 23.3 degrees at one natuical mile, respectively. The mean TSCT and FTE quantities show a value of 3.0 degrees and 3.3 degrees at one nautical mile, respectively. The ASE angular quantities at one nautical mile indicates a mean value of -.28 degrees and a one-sigma of 11.37 degrees. A first look at the ASE angular quantities might indicate large airborne system errors but a comparison of the linear and angular quantities indicate otherwise. Although in most cases large angular quantities were measured, linear errors were never greater than .5 nm.

Figures 5.16-5.19 are graphical representations of Airborne System Error (ASE), Along Track Error (ATE), Flight Technical Error (FTE), and Total System Cross Track Error (TSCT). The mean value and mean ±2 sigma values are plotted vs. distance to beacon. The significance of these figures is strictly with reference to airspace requirements. Figure 5.16 indicates that the Airborne System Error (ASE) mean ±2 sigma value is virtually constant with range from the beacon, converging only slightly

Table 5.15 NAFEC ARA Single Beacon Approach Statistical Summary

	$\overline{X}$(nm)	σ(nm)	DATA POINTS	APPROACH SEGMENTS
ARA ATE				
LONG	-.0397	.2357	2172	25
SHORT	.0793	.1637	615	15
OFFSET	.1139	.2162	328	9
TOTAL	.0002	.2295	3115	49
ARA ASE				
LONG	-.1824	.5174	2172	25
SHORT	-.1168	.3306	615	15
OFFSET	.0154	.3687	328	9
TOTAL	-.1487	.4757	3115	49
FTE				
LONG	.2790	1.1644	2172	25
SHORT	.4001	.7155	615	15
OFFSET	-.0417	.8493	328	9
TOTAL	.2692	1.0656	3115	49
TSCT				
LONG	.0966	1.1067	2172	25
SHORT	.2833	.7017	615	15
OFFSET	-.0263	.9746	328	9
TOTAL	.1205	1.0289	3115	49

Table 5.16 ARA Single Beacon Approach Data Aggregated at One Nautical Mile Intervals

		LINEAR ERRORS				ANGULAR ERRORS			
NM	PTS	ATE	TSCT	FTE	ASE	TSCT	FTE	ASE	
1	39	.1047	.0521	.0570	-.0049	2.9811	3.2615	-.2812	MEAN
		.1735	.4256	.4299	.2010	23.0558	23.2646	11.3677	STD
2	48	.0433	.0379	.1122	-.0743	1.0844	3.2105	-2.1284	MEAN
		.1821	.5659	.5790	.2187	15.7976	16.1454	6.2416	STD
3	47	.0174	.0262	.1367	-.1105	.5007	2.6095	-2.1097	MEAN
		.1994	.6952	.6807	.2312	13.0469	12.7848	4.4078	STD
4	46	.0419	.0714	.1713	-.0999	1.0223	2.4515	-1.4303	MEAN
		.2170	.8516	.8273	.2691	12.0191	11.6857	3.8487	STD
5	45	.0445	.1205	.2218	-.1013	1.3808	2.5404	-1.1608	MEAN
		.1913	1.0014	.9470	.2914	11.3253	10.7242	3.3357	STD
6	36	.0196	.1234	.2823	-.1589	1.1786	2.6937	-1.5166	MEAN
		.1302	.9251	.9199	.3358	8.7654	8.7165	3.2037	STD
7	26	-.0046	.0780	.2947	-.2167	.6381	2.4104	-1.7732	MEAN
		.1708	1.1036	1.1286	.3513	8.9593	9.1591	2.8732	STD
8	25	-.0091	.0013	.2300	-.2287	.0093	1.6471	-1.6377	MEAN
		.1600	1.1511	1.1498	.3840	8.1881	8.1792	2.7481	STD
9	25	-.0206	.0187	.1302	-.1115	.1189	.8289	-.7100	MEAN
		.1853	1.2845	1.3071	.3447	8.1225	8.2637	2.1934	STD
10	21	.0021	-.0637	.1952	-.2588	-.3647	1.1181	-1.4826	MEAN
		.2332	1.2125	1.2862	.3794	6.9134	7.3291	2.1725	STD

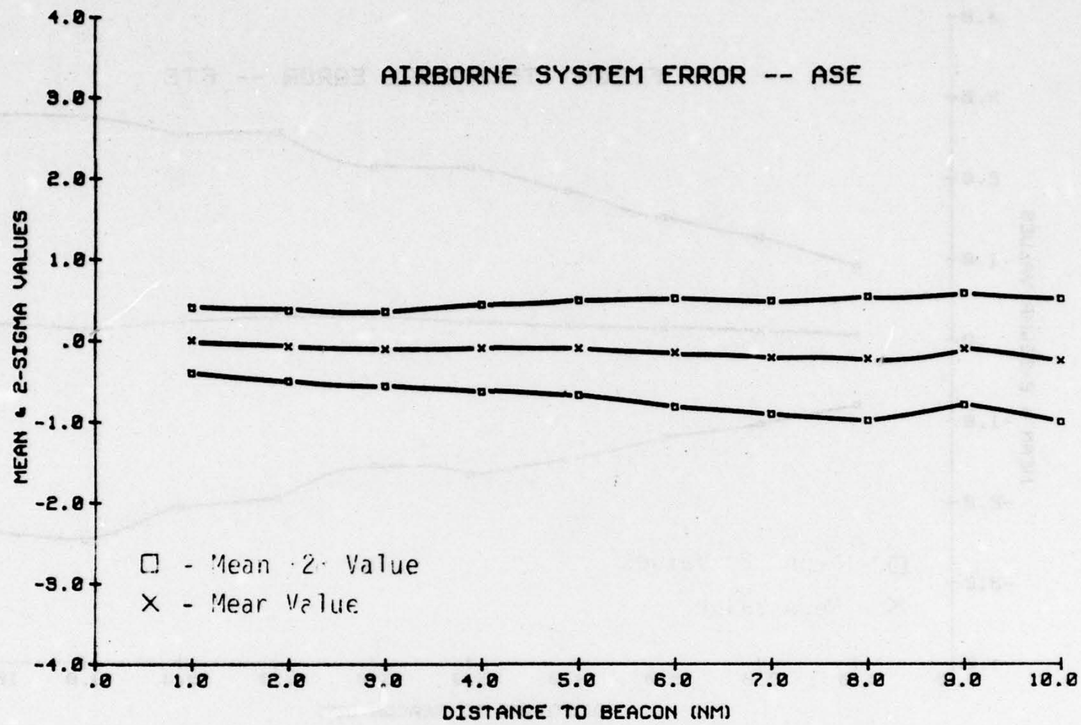


Figure 5.16 Airborne System Error Statistics: Mean, Mean ± Two-Sigma Values

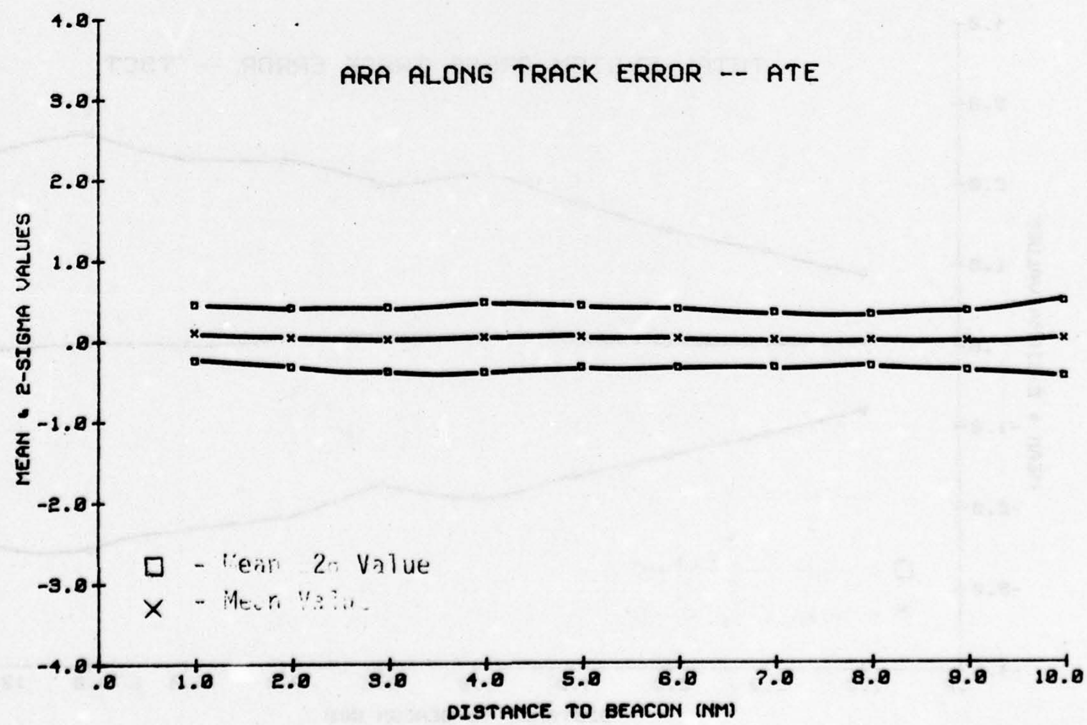


Figure 5.17 ARA Along Track Error Statistics: Mean, Mean ± Two-Sigma Values

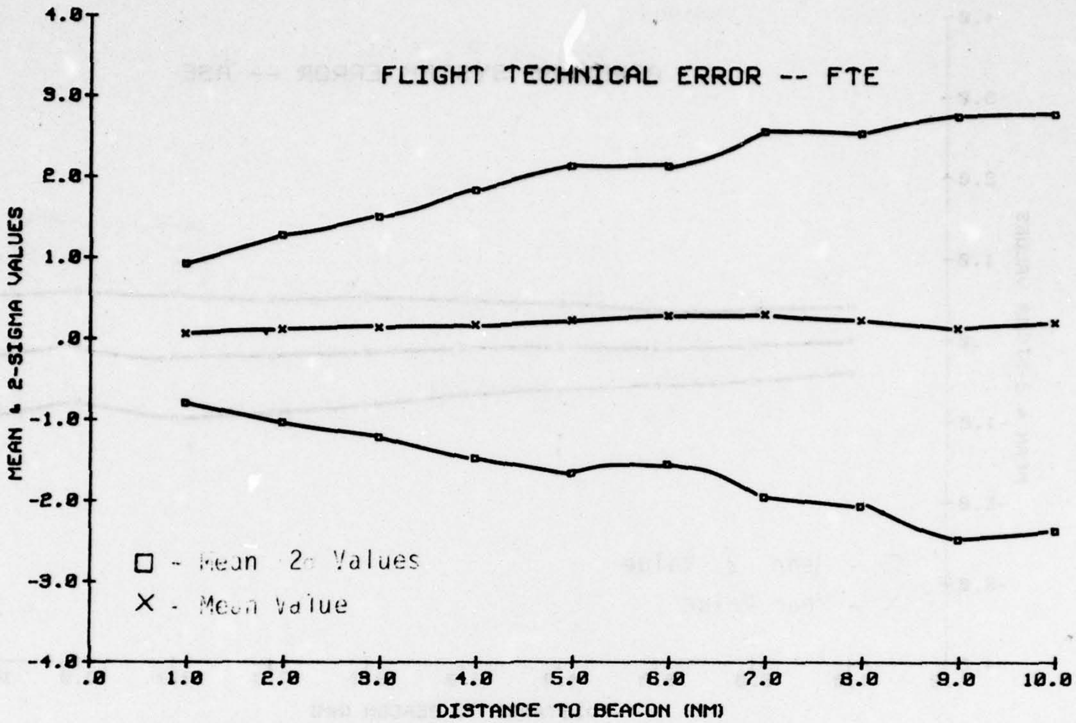


Figure 5.18 Flight Technical Error Statistics: Mean, Mean ± Two-Sigma Values

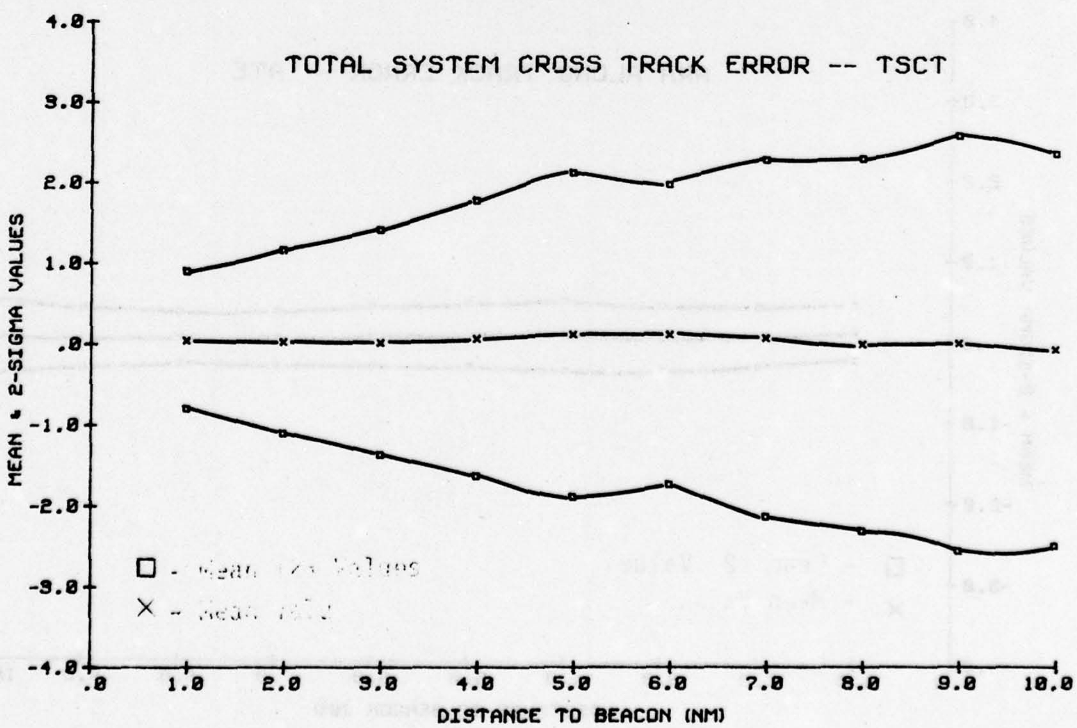


Figure 5.19 Total System Cross Track Error Statistics: Mean, Mean ± Two-Sigma Values

as the target is approached. Figure 5.17 indicates that the ARA Along Track Error (ATE) mean ±2 sigma value is constant with respect to range to the beacon. Figures 5.16 and 5.17 show that the airborne system is quite consistent and dependable regardless of range to landing zone. Figure 5.18 indicates that the Flight Technical Error (FTE) mean ±2 sigma quantities converge as the beacon is approached. The Total System Cross Track (TSCT) mean ±2 sigma quantities represented in Figure 5.19 also converge as the beacon is approached. Figures 5.18 and 5.19 show that as the beacon is approached less airspace is required to assure a 95% confidence level.

Figures 5.20-5.23 are histograms of ARA TSCT, FTE, ASE, and ATE for all of the single beacon approaches flown at NAFEC. Only data within 10 nm of the beacon is included. These histograms represent the error quantity distributions for the four error quantities mentioned previously. Figure 5.20 is a histogram of TSCT and shows that the quantities are skewed slightly to the right. Figure 5.21 shows that the FTE quantities are also skewed slightly to the right. Figure 5.22 shows that the ATE quantities are skewed slightly to the left, while the ASE distributions appear to be normal.

Table 5.17 summarizes the target width size aggregated at one nautical mile intervals for all of the ARA Single Beacon Approaches. The quantities show that the target size displayed was consistently large. The target width values show a mean of 13.4 degrees and a one-sigma of 3.6 degrees at ten nautical miles. At one nautical mile they show a value of 15.5 degrees and a one-sigma of 4.6 degrees. The total target width analysis showed a mean value of 13.2 degrees and a one-sigma of 4.1 degrees.

Table 5.17 ARA Single Beacon Approaches Target Width Analysis

Distance To Target	# of Points	Mean Value (Degrees)	One-Sigma Values (Degrees)
1	30	15.46	4.62
2	31	13.68	3.44
3	31	13.80	3.73
4	31	12.30	4.18
5	30	12.89	3.89
6	29	13.09	3.74
7	27	11.35	4.07
8	25	11.88	4.80
9	25	13.59	3.97
10	24	13.43	3.63
Total	283	13.18	4.10

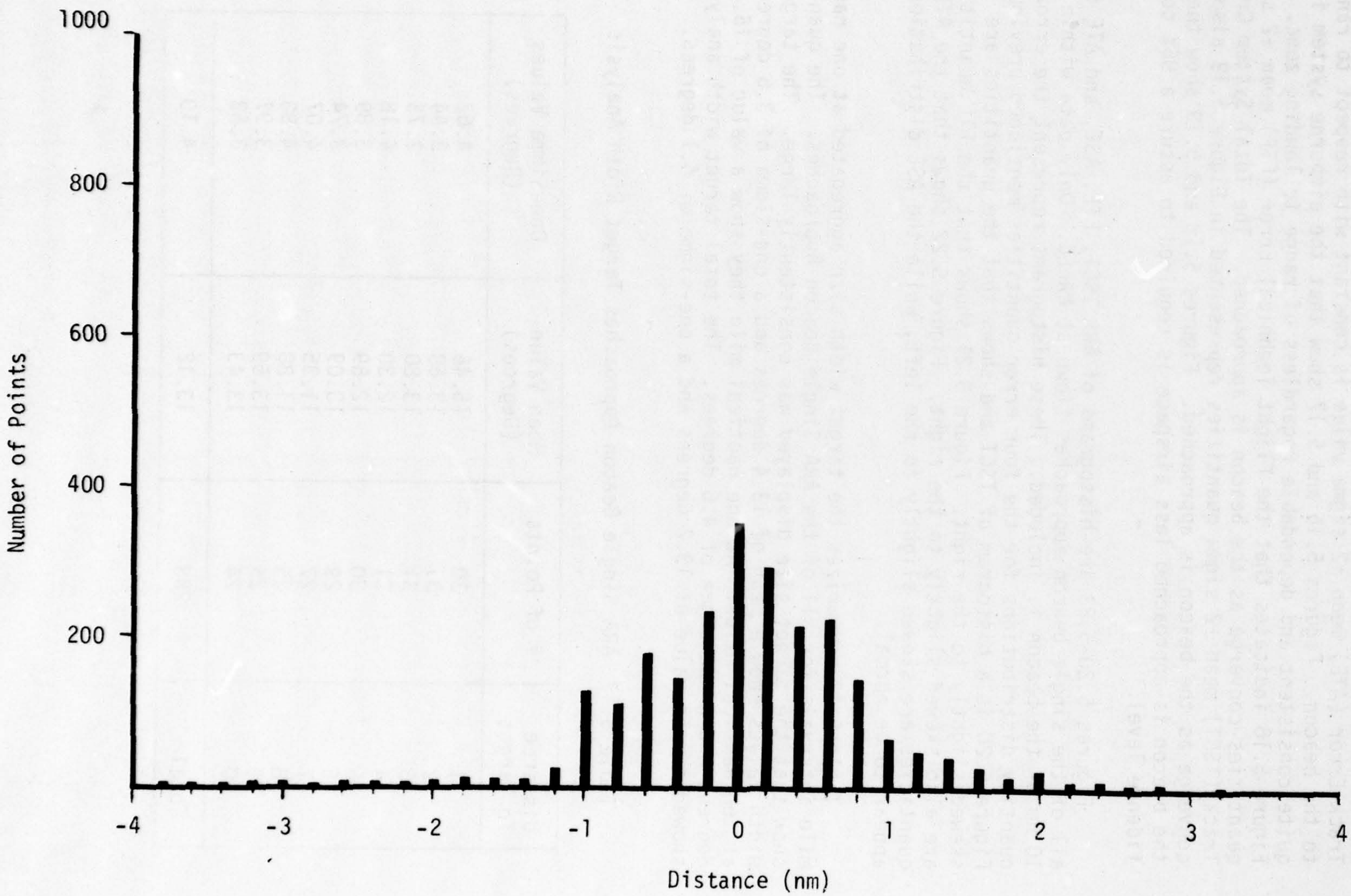


Figure 5.20 Histogram of ARA Total System Cross Track Error

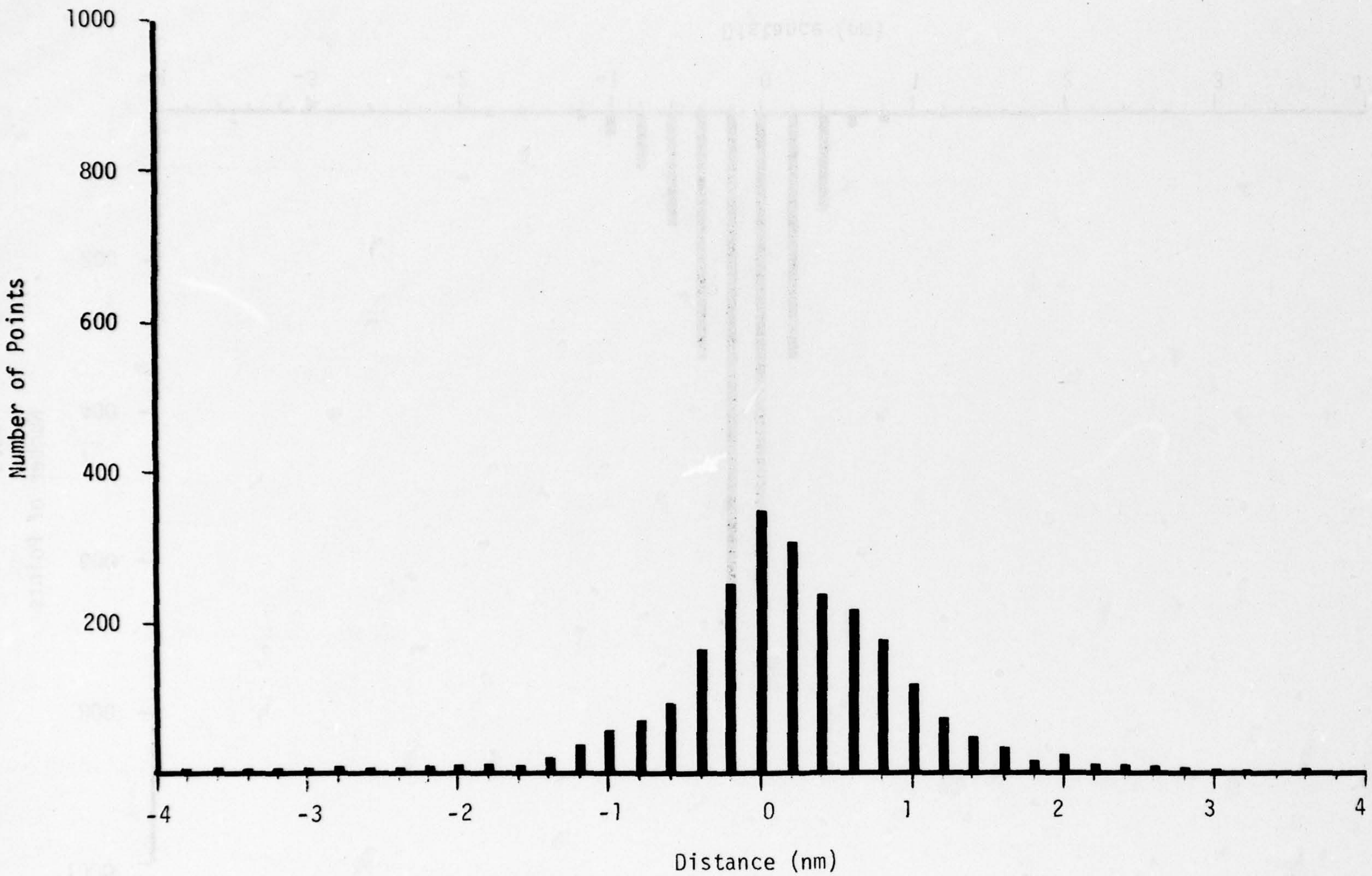


Figure 5.21 Histogram of ARA Cross Track Flight Technical Error

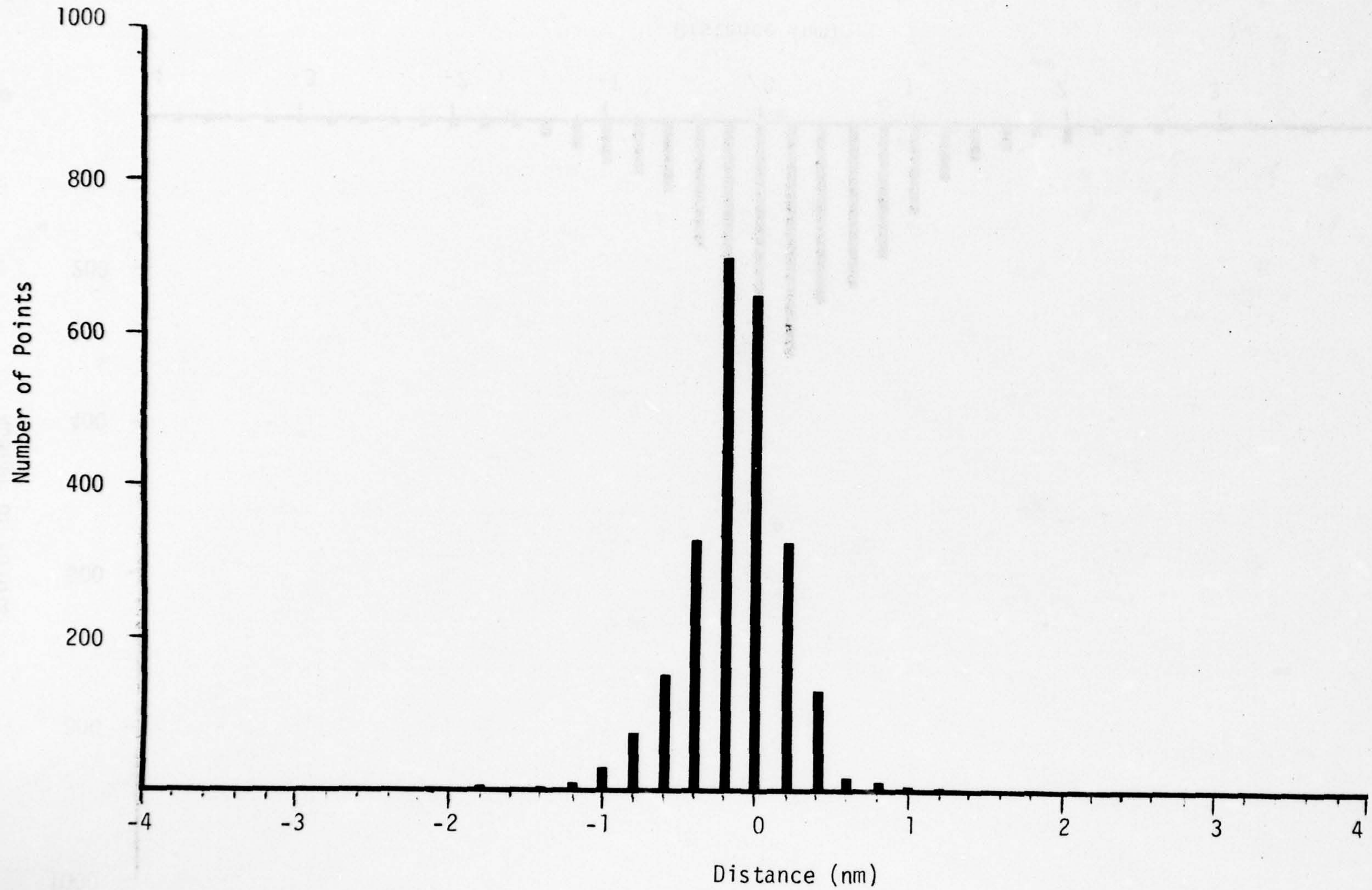


Figure 5.22 Histogram of ARA Airborne System Error

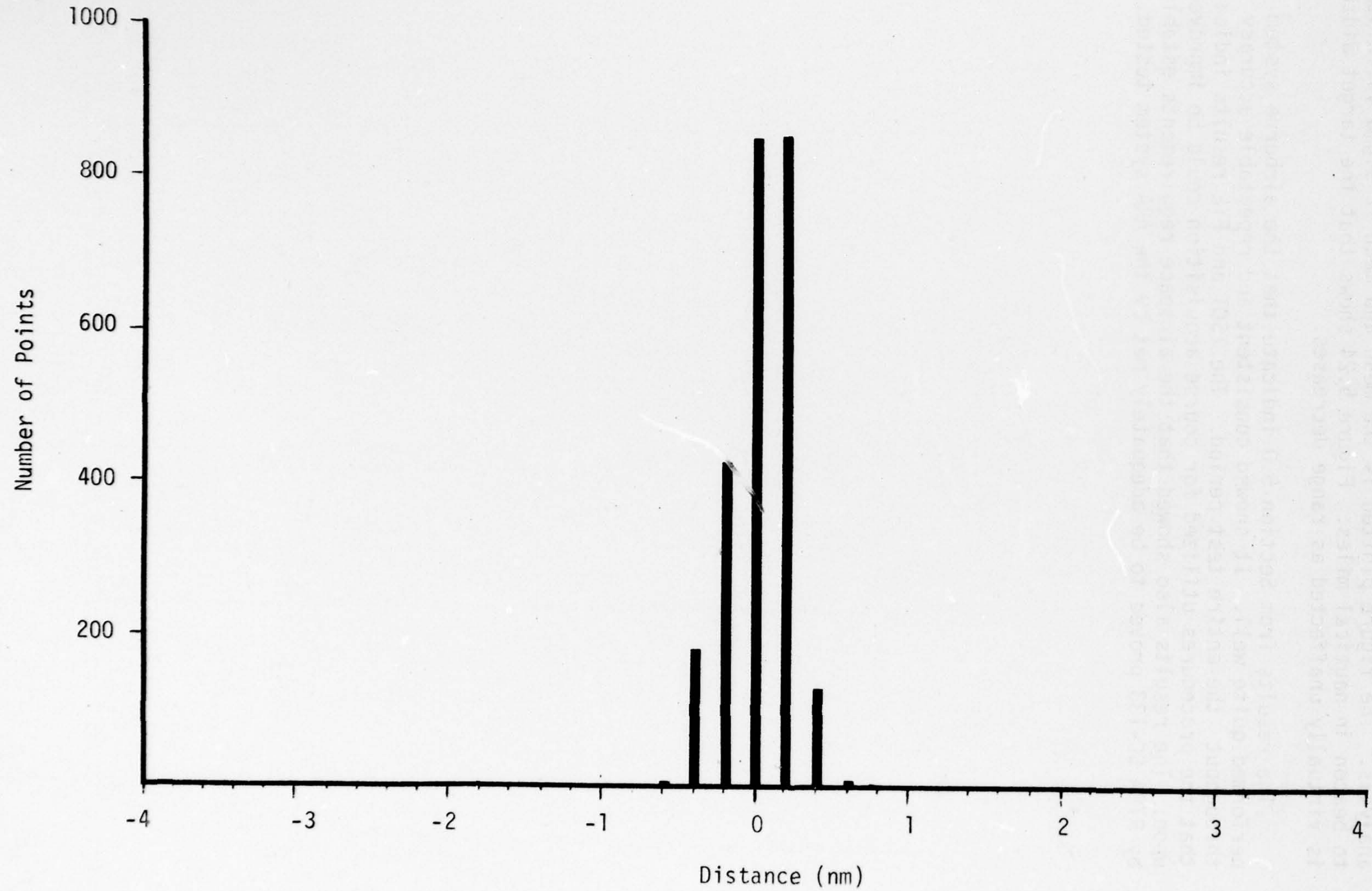


Figure 5.23 Histogram of ARA Along Track Error

Figure 5.24 is a graphical representation of the target width analysis. The figure plotted is the mean and mean ±2 sigma vs. distance to beacon in nautical miles. Figure 5.24 shows that the target width is virtually unaffected as range decreases.

The results from Section 5.0 indicate that the airborne system performed quite well. It showed consistent and repeatable accuracy throughout the entire test period. The TSCT and FTE results indicate that the procedures utilized for course acquisition could be improved upon. The results also showed that the airspace requirements established by RTCA SC-133 proved to be adequately met by the ARA system tested.

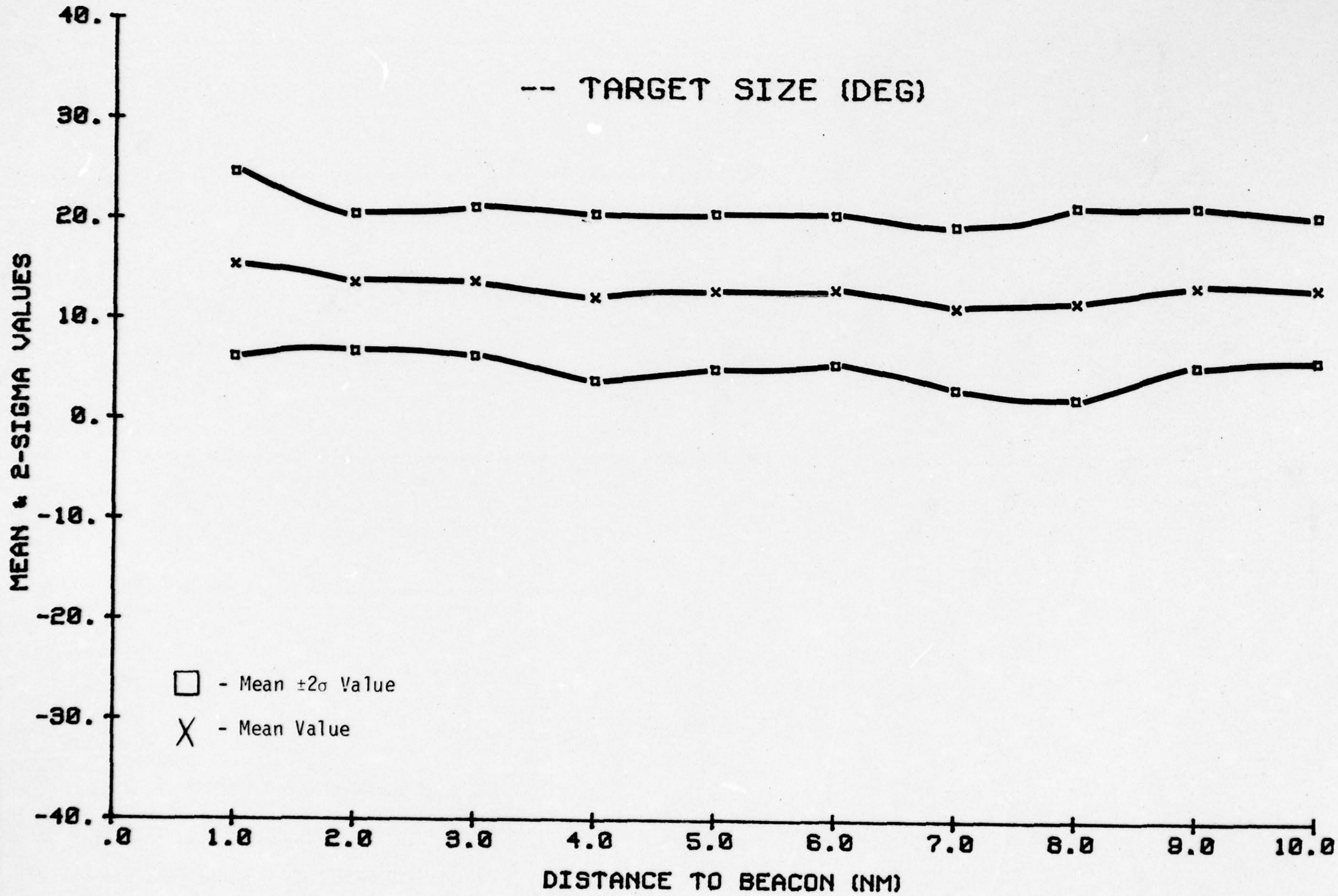


Figure 5.24 ARA Target Size Statistics: Mean, Mean ± Two-Sigma Values

6.0 IN-FLIGHT CONSIDERATIONS

The following section will describe the procedural impact of Airborne Radar Approaches on the pilot and copilot and operational problems encountered during the flight test. Items such as pilot/copilot workload and blunders during the Airborne Radar Approach flight test will be assessed. Training concepts for airborne radar approaches will also be discussed. These training concepts include use of the airborne radar as an approach aid in both the skin paint and single beacon mode.

6.1 PILOT/COPILOT WORKLOAD

The pilot/copilot workload involved in flying an Airborne Radar Approach is quite heavy. Based on qualitative observations during the entire test program, the Airborne Radar Approach was concluded definitely to be a two pilot operation. The Airborne Radar System is a good approach aid, but for the pilot to interpret the given information, and to constantly adjust the radar display controls, requires considerably more effort than any other standard non-precision approach using conventional radio navigation aids. Probably the greatest workload aspect of the airborne radar tested were the constant adjustment required of the gain, tilt, and radar range controls. Gain adjustment was a never-ending process during the entire approach. For the specific system tested, the gain must be constantly adjusted to keep the target size at a optimum*. There were, however, optimum tilt settings that were found to apply during the approaches, e.g., -2 degrees was found to be the optimum setting. Although the -2 degrees tilt setting worked for the entire approach, a constant tilt setting was not necessarily the best recommended procedure for flying the approach. Theoretically, as the aircraft approaches the target the tilt should be lowered so that the antenna is scanning the target within its vertical beam width. The wide vertical beam width results in a low sensitivity to tilt setting.

The copilot's workload consisted primarily of three distinct items:

- Radar target interperation in relation to intended course
- Operation of radar display controls
- Range and heading call-outs to the pilot

The radar target interpretation is strictly empirical for many reasons. First, in the beacon mode with the STAB indicator on the 120 degree setting, there are only azimuth lines every 30 degrees displayed on

*The Sensitivity Time Constant (STC) adjustment for this particular radar unit was not set properly. This fact was later verified by the Bendix Corporation upon completion of the flight test program.

the screen. Therefore, if the target lies between the azimuth lines it is the copilot's responsibility to interpret his position relative to zero azimuth. Second, the copilot must assume that the center of the beacon return displayed on the screen is the intended target. As shown in Section 5.0, the target width analysis shows a mean value of 13.18 degrees and a one sigma 4.10 degrees. It is apparent that this large target width would put a limitation on the pilot's interpretive judgement of actual position with relation to the intended course. Another cause for error in display interpretation is the slow update rate of the airborne radar. Five seconds is required for the radar to sweep in one direction. Therefore, aircraft heading could change considerably while the displayed target appears to stay stationary. All of the above factors greatly increase the workload of the copilot, making his position as navigator a fulltime job.

The pilot's workload was quite different from that of the copilot. It was the pilot's sole responsibility to fly the aircraft and handle all Air Traffic Control (ATC) Communications. As mentioned earlier the pilot was unhooded throughout the entire flight test. This was done for a particular reason: along with his other responsibilities the pilot needed to be aware and look out for all other traffic in the area. The observer and crew chief onboard the helicopter also aided in watching for traffic, but it was the major responsibility of the pilot to do so. Since the traffic around the NAFEC airport was fairly dense, many times there was a considerable amount of confusion in the pilot/copilot and pilot/ATC communications. Often times this delay in communications from the copilot to the pilot resulted in a deviation from intended course or a delayed correction to reacquire the intended course. Another pilot workload factor introduced during the flight occured on the final approach course. Because of the slow airspeed (50 knots), handling of the helicopter became a problem particularly in crosswind conditions.

Pilot and copilot workload rating sheets were given to each crew member at the end of every flight. The pilots rated themselves on the level of mental and physical effort applied in flying each Airborne Radar Approach. The copilots rated themselves on the level of mental and physical effort applied in navigating and vectoring each Airborne Radar Approach. Table 6.1 summarizes the responses which the pilot and copilot indicated on the workload rating sheets.

Table 6.1 Pilot/Copilot Workload Ratings

	Number of Flights	
Workload Level	Pilot	Copilot
Very Low	0	0
Low	0	0
Moderate	7	4
High	3	5
Very High	0	1

As shown in Table 6.1, the pilots considered seven of the ten flights to have a moderate workload while three were considered high. The copilots on the other hand indicated that only four of the ten flights had a moderate workload while the other six were considered either high or very high.

Baseline data was acquired to substantiate the fact that the Airborne Radar Approaches create a high cockpit workload. RNAV approaches to NAFEC's runway 04 were conducted to achieve a comparison. Of the four RNAV approaches flown, the workload ratings ranged from low to moderate, indicating a more relaxed environment. The Airborne Radar Approach constitutes a high workload situation. This indicates that it is a two pilot operation only, and cannot be reliably conducted by a single pilot with present equipment and techniques.

6.2 OPERATIONAL DIFFICULTIES EXPERIENCED DURING THE TEST

The pilot/copilot blunders encountered during the test were few. Most of the problems encountered during the test were operational in nature. The main pilot/copilot blunders encountered were of two types; improper adjustment of display controls and improper execution of planned approach procedures. The display control problems encountered were as follows: the scale being changed too soon leaving no target on the screen, improper gain adjustment, often making the target disappear, and improper adjustment of the tilt control, making close-in navigation difficult. Operational problems encountered during the flight test program were limited in number. On the first flight of the test program the pilots were supplied with the incorrect RNAV waypoint coordinates. As the program progressed problems were encountered with the transponder beacons. At times the ground based beacons were either inoperative or weak and intermittent. On two occasions it was noted that two beacon returns appeared on the screen creating only slight confusion at first. Table 6.2 is a detailed account of all the operational problems encountered during the single beacon ARA flight test program.

6.3 PILOT/COPILOT TRAINING CONCEPTS

Although the civil application of airborne radar approaches is a relatively recent development, the military services have been training crews in airborne directed approaches for a number of years. Consequently the development of civil training concepts can draw heavily on the experience gained by the military in the establishment of their training programs.

Conducting an airborne radar approach requires an in-depth understanding of the principles of radar operation, radar interpretation, control characteristics of the particular airborne radar being used, and operational difficulties which can be expected throughout the approach. For the typical pilot, these concepts are outside the realm of his experience. The concepts are relatively basic, however, and lend themselves to a course of instruction which would be quick and easy to administer to the average pilot.

Table 6.2 Operational Problems Experienced During the Flight Test Program

FLIGHT	DATE	LOCATION	PILOT/COPILOT BLUNDERS	ATC/COMMUNICATION PROBLEMS	OPERATIONAL PROBLEMS	DISPOSITION
1.	10/24/78	Airport			1. RNAV inoperative on copilot's side necessitating use of the VOR on the pilot's side for navigation 2. VOR on the copilot's side inoperative 3. Pilot supplied with the wrong waypoints for flight routing	1. 4 approaches 2. Baseline flight 3. Reaccomplished on 12/12/78, 12/13/78 and 12/14/78
2.	10/25/78	Airport	1. Pilot climbed to 2000 feet instead of 1000 ft for beacon acquisition 2. Copilot misread the radar range marks on second approach	1. ATC communication problems encountered		1. 4 approaches 2. First beacon approaches flown 3. Reaccomplished on 10/27/78, 12/13/78 and 12/14/78
3.	10/25/78	Airport				1. 3 approaches 2. Reaccomplished on 10/31/78 and 11/3/78
2.	10/27/78	Airport	1. Radar tilt adjusted too low on first approach			1. 4 approaches 2. Reaccomplished on 12/13/78 and 12/14/78
3.	10/31/78	Airport	1. Radar tilt not adjusted on last approach	1. ATC communication problems encountered		1. 4 approaches 2. Reaccomplished on 11/3/78
3.	11/ 3/78	Airport				1. 4 approaches
4.	11/14/78	Remote Offshore	1. *Beacon temporarily lost on third approach due to premature radar scale advance*			1. 3 approaches
5.	11/15/78	Remote/ Offshore	1. Beacon acquired late on first and third approaches, apparently due to poor gain control adjustment 2. Missed approach executed in the wrong direction on the third approach			1. 4 approaches
6.	11/20/78	Remote/ Offshore			1. Beacon inoperative probably due to the accumulation of water in the power supply	1. 2 approaches
7.	11/29/78	Remote	1. On first and second approaches, pilot did not descend to 500 feet after passing the overhead target. 2. On first approach pilot did not slow to 50 knots on final approach course.			1. 3 approaches
8.	12/ 1/78	Remote	1. Lost beacon for four sweeps during last approach, probably due to gain control problems		1. RNAV inoperative. Approach fixes were acquired by using *dead reckoning procedures* 2. Beacon inoperative for first approach	1. Attempted 3 approaches - aborted 1
9.	12/12/78	Remote/ Offshore			1. Beacon not acquired on first approach until aircraft was ten miles out 2. Beacon weak on all approaches 3. DME intermittent on baseline approach	1. 4 approaches and 1 baseline approach
10.	12/13/78	Offshore			1. On first approach to the offshore site two returns appeared on screen. Crew successfully determined the proper return for navigation	1. 3 approaches and 1 baseline approach
2.	12/13/78	Airport	1. Multiple ground returns in vicinity of airport due to poor gain control during first approach. Consequently beacon was not acquired until the aircraft was 12 nm out			1. 3 approaches
10.	12/14/78	Offshore, Airport		1. ATC communication problems *in the airport area*		1. 1 offshore approach, 2 airport approaches, and 1 RNAV baseline approaches

The first item to be included in a generalized ARA course of instruction should be a overview of radar theory. This will provide a review for those pilots which have already been exposed to airborne radar theory and, at the same time, allow those pilots with no radar experience to establish a baseline starting point in common with their more experienced counterparts. Inclusion of radar theory will also correct any misconceptions which may be prevalent at an early stage in the overall ARA training. Instruction in this phase should include, but not be limited to, a brief overview of basic principles of radar operation, definitions and explanations of characteristic terms, and a generalized overview of the concept of secondary radar principles (beacon returns). Instruction should be given in a relaxed, open environment and student discussion and participation should be encouraged.

The second phase of instruction which should be included involves the specific operation of the airborne radar the students will be using for their airborne approaches. Concepts in this phase should be related to the generalized theory learned in the first phase to as large an extent as possible. Emphasis should be placed on the function of individual control switches, interrelationships between control inputs, and specific operational characteristics, both control and display, of the system being discussed. The importance of this phase cannot be over emphasized as it will form the basis for not only the overall understanding of the radar system being used but also the translation of the generalities of theory (from phase one) into operational realities. This is often a difficult transition to make, particularly in an abbreviated course such as is being described here. Students should have a solid understanding of this phase before proceeding to the next one.

The third phase, detection and corrective action for common operational radar intricacies, covers a wide variety of interrelated subjects, ranging from the establishment of proper drift correction angles to radar scope tuning concepts. The difficulty associated with this phase of instruction will be the presentation of these concepts in a logical and organized manner. The tuning of the radar scope involves the use of gain control, tilt control, and, in some cases, intensity control. During the course of an approach, as the target beacon approaches the vertex of the scope, gain may have to be reduced to counteract the influence of the "bright spot" generally associated with radar displays. As the range scale is decreased, placing the beacon further from the vertex, gain again may have to be readjusted. Unless the radar is supplied with automatic tilt control, tilt will have to be adjusted throughout the approach to obtain optimum display characteristics. This will be particularly noticable during the latter stages of the approach. Wide vertical beam width can compensate for the necessity to make continuous fine tilt adjustments, but this increase in vertical beam width could possibly affect the accuracy of the horizontal beam width. Intensity and gain controls also have an effect on beacon return size to be displayed. These displays are caused by side lobe radiation from the aircraft transmitter/receiver unit and can be minimized by proper gain and intensity settings. The most common problem associated with ARAs is the establishment of proper drift correction angles, particularly when using a display without a moveable

azimuth cursor. Although the principles should be taught in this phase of classroom instruction, consistent performance is a product of operational experience. Overall, this phase of instruction will be the most difficult to accomplish in the classroom environment and many of the principles taught here will not become functionally ingrained until the student has had the opportunity to experiment with them in the operational environment.

The fourth phase of instruction, the establishment of recommended operating procedures, should serve as an overall synopsis of the previous three phases. Student participation can be encouraged by allowing them to make recommendations for the operating procedures they feel should be included. This procedure will require a certain level of overall guidance however, due to the operational experience level of the student.

The concept of airborne radar approaches is a valid, workable concept if proper training is established as a prerequisite requirement. As discussed earlier in this report, the high workloads encountered, particularly during the final approach phase of flight, necessitates the division of the load between two crew members. In the initial phase of this study, ARAs were attempted using a single pilot concept. Results conclusively showed that single pilot ARAs were operationally infeasable. It is not necessary to have two pilots as the crew composition, however, the flight rating of the individuals in reality has no significance; thus the second crew member can be either a pilot or a navigator. At the present time the Air Force is conducting training in airborne radar approaches on a routine basis. The dual computer based navigation system of the F-111 has the capability of simulating an ILS type of approach using radar cursor placement as the primary position input for the approach. The older B-52 has been conducting Airborne Radar Directed Approaches (ARDA) for a number of years. This approach simulates a surveillance type of approach, due to the inability to generate a glideslope indication. The principles of operation are similar to those used in this study with the exception that directional signals are automatically fed to the pilot electronically on a CDI type of display. Radar crosshair placement is accomplished by the radar navigator and updated as necessary. This procedure is extremely effective and Stategic Air Command (SAC) crews are required to show proficiency in this area during the course of their annual proficiency checkrides.

The concept of airborne radar approaches is a valid one from the viewpoint of aircrew and operational factors. It should be recognized, however, that workload considerations demand that these procedures be considered a two crew member operation. Single pilot airborne radar approaches demand too much of the pilot's time, particularly during the critical approach and landing phase. As the crews became more proficient in the prescribed procedures throughout the course of this study, a decrease in significant pilot/copilot blunders can be noted. This indicates that proper training coupled with a minimum amount of experience will produce acceptable levels of blunder errors in the overall ATC system. The complete failure of the single pilot concept

in the initial phases of the study is a significant indication that single pilot operations are not acceptable for inclusion into the general ATC environment, given the present state of the art of airborne radar systems. The operational problems encounted were, for the most part, typical of this kind of test, and aside from reducing the total data base slightly, have little or no impact on the final results. Aircrew training appears to be the key to establishing airborne radar approaches as an accepted concept for inclusion in the ATC environment. The four phases of instruction presented represent a "best guess" estimate and should not be considered to be a definitive statement of total training requirements. Further testing and analysis will yield improved understanding of aircrew training requirements as well as specific airborne radar approach intricacies as yet unknown.

7.0 SUMMARY OF ARA PERFORMANCE

This section summarizes the technical and operational performance of the Airborne Radar Approach (ARA) System. This summary includes the testing performed in the skin paint and single beacon approach mode.

7.1 TECHNICAL PERFORMANCE

The technical performance objectives stated below are in response to the RTCA SC-133 "Minimum Operational Performance Standards" (MOPS) requirements. The summary of quantitative data shown was presented in detail in Section 5.3.

7.1.1 Range Performance

The single beacon approach testing showed a maximum acquisition range of 21 nm at an altitude of 1000 feet with the beacon at ground level. During the offshore testing the beacon was situated approximately thirty feet from the water's surface, which allowed a consistent maximum acquisition range of 30 nm at 1000 feet altitude. The minimum range at which the beacon could be tracked and displayed was .7 nm at 200 feet. These results were both qualitatively and quantitatively determined from the data collected during the single beacon approach testing at NAFEC. No attempt was made during these tests to specifically determine the range performance during adverse weather conditions such as precipitation.

The reflector and skin paint tests showed that only objects with large cross-sectional areas could be distinguished from the surrounding ground clutter. It was found through qualitative observation that the large reflector (36,153 m^2 theoretical radar cross section area) could not be identified until 5 nm. The small reflectors (715 m^2 theoretical radar cross section area) were completely indistinguishable from ground clutter. The lighthouse presented a target of such large radar cross section (approximately 100,000 m^2) against a relatively low clutter background that it was almost always displayed at a range of 20 nm and an altitude of 1000 feet. However, the lighthouse target was virtually indistinguishable from the targets presented by nearby ships and was often unidentifiable until visual contact was established.

7.1.2 Bearing Accuracy

The Airborne Radar Approach System was determined to have a mean accuracy in bearing with which a target can be displayed of -1.2 degrees at five nautical miles from the beacon. The ARA system bearing measurement also showed a one-sigma value of 3.3 degrees. SC-133 requires an accuracy of ±3°. Accuracy data at the ten nautical mile point showed a mean value of -1.5 degrees and a one-sigma of 2.2 degrees.

7.1.3 Display Readability

No specific tests were performed in this area. Qualitative observations showed that in direct sunlight the display was washed out, making it totally unreadable. In other forms of intense lighting the display readability was degraded but still could be resolved.

7.1.4 Display Resolution

Display resolution is inherently a system design characteristic, therefore the data obtained was to the same degree subjective in nature. As shown in Section 5.5, a target width analysis study showed a mean value of 13.2 degrees and a one-sigma of 4.1 degrees. These values were obtained for all of the approaches flown during the single beacon testing. It was determined that even though the target displayed would have preferably been smaller, qualitatively it appears that the displayed size did not affect the pilot's interpretation of the radar display. It was, however, difficult for the pilot to identify laterally separated beacons, while longitudinally separated beacons could be distinguished at a 5000 foot spacing.

7.2 OPERATIONAL PERFORMANCE

The operational performance objectives were threefold, first, to determine what effect ground clutter had in the mapping mode, second, to determine if reflectors could be distinguished from surrounding ground clutter, and third, to assess the overall performance of the airborne system in the beacon mode.

7.2.1 Target Discrimination And Identification In The Mapping Mode

Ground clutter in the mapping mode offered some operational problems during the skin paint testing. While executing approaches to the lighthouse it was often times difficult to distinguish between ships and the lighthouse. At the airport site, during the reflector testing the small reflectors could not be discerned from the ground clutter and the large reflector was only visible when very close to the target (five nautical miles).

7.2.2 Reflector Discrimination

Landside reflector testing showed that large reflectors are required to paint identifiable returns. Because of the small cross-sectional area of the small reflectors, they could not be distinguished from surrounding ground clutter. Therefore, it is unknown as to whether or not reflectors used in various geometric patterns enhance track keeping. The large reflector painted a return but poor construction tolerances resulted in a loss of reflector efficiency. This accounts for the small range at which they were acquired.

7.2.3 Performance in Beacon Mode

The beacon mode tests proved very successful at all of the operational sites. The displayed target size was large but this size did not present an operational problem. Track acquisition proved to be a problem on some of the approaches but never resulted in any serious pilot blunders. Constant monitoring of the gain, tilt and range controls was required by the copilot to maintain proper aircraft heading. It was found on two occasions that multipath returns and unidentified beacons, caused some minor problems in target identification. Although the multipath returns and unidentifiable beacons seen during the testing caused few problems, the potential for identification problems certainly exists in a city helipad environment.

The along-track accuracy showed a mean value of 0.0 nm and a one-sigma of .23 nm. The cross-track accuracy showed a mean value of -.15 nm and a one-sigma of .48 nm. These quantities reflect a system accuracy that is quite good, which also correlates to the qualitative assessment of the system.

8.0 CONCLUSIONS

The major conclusions from the operational flight test evaluation of the Airborne Radar Approach (ARA) system are summarized in this section. These conclusions are, by intent, qualitative in nature. The quantitative results from which these conclusions were reached are summarized in Section 7.0 and discussed in depth in Section 5.0. These conclusions are organized to represent a qualitative summary of the detailed evaluation objectives presented in Section 3.0.

- Skin Paint Mode

  1) The Airborne Radar Approach System's ability to distinguish desired landside landmarks is quite limited.

  2) Offshore targets such as buoys, lighthouses, and oil rigs paint bright returns, but are indistinguishable from boats, etc.

- Reflector Mode

  1) The Airborne Radar Approach System requires very large reflector cross sections to positively identify landside targets.

  2) Multiple small reflector targets in a pattern provided no identifiable return on the radar screen, therefore no approach path orientation information was available.

- Single Beacon Mode

  1) The Airborne Radar Approach System performed accurately at the airport, remote, and offshore sites in the single beacon mode.

  2) The Airborne Radar Approach System range performance is adequate at minimum ranges, but maximum range performance at 1000 feet should be improved as regards the requirements of RTCA SC-133.

  3) The Airborne Radar Approach System bearing accuracy proved to be very acceptable.

  4) The display readability of the Airborne Radar Approach System is poor under high ambient light conditions.

  5) No explicit testing was accomplished to determine the impact of precipitation on system performance

6) While large target widths were usually encountered, this did not affect the operational performance or display interpretability of the Airborne Radar Approach System.

7) Multipath returns and unidentifiable beacons offered some operational problems.

8) The lateral airborne system cross track error was found to be quite good, while the flight technical error values indicated that the procedures used for track acquisition attributed to large FTE quantities.

9) Data showed that TSCT and FTE errors reflected the tendency to use ARA as a homing device rather than a cross track error "nulling" device.

10) The Airborne System along track error was very good, again confirming the quality of the airborne system itself.

11) The pilots utilized for the Airborne Radar Approach flight test performed very well. The workload involved in flying the approach necessitates two crew members, not one. The pilot/copilot blunders encountered were not serious but the procedures utilized could be improved upon.

- Beacon Mode vs. Skin Paint Mode Comparison

  Operationally both modes of operation have their own specific problems. The Airborne Radar Approach System is an operationally viable navigation aid to landing. The skin paint mode offers the ability to identify obstacles that surround the landing site, but offers no positive identification of the site itself. The beacon mode on the other hand offers positive site identification, but no obstacle discrimination.

9.0 ARA TRACK ORIENTATION IMPROVEMENTS

During the course of this study, it was observed that operators had, on numerous occasions, difficulty in acquiring and tracking the desired inbound final approach course. This was due primarily to the lack of a course display system compatible with standardized pilot course displays such as CDI or RMI indications. Ideally, a tie-in to the on board flight director system would provide the most compatible display system. This would require extensive radar system modification and the provision for additional processing capability, which could result in excessively high user costs. Because of these economic considerations, three low cost techniques have been developed to enhance acquisition and tracking capabilities. These techniques are presented and discussed in detail in this section.

9.1 LOW USER COST ALTERNATIVE TECHNIQUES

A. DOUBLE BEACON TECHIQUE

The double beacon technique for course identification involves the use of two independent ground beacons to establish visual reference indications of the desired final approach course on the airborne radar display. It is the functional equivalent of the multiple-reflector technique used in the ground mapping mode. Both techniques have application primarily to landside operations. Reflectors are usually unnecessary for offshore oil rig operations since the basic target itself presents a distinctively bright return on the airborne equipment. Single beacon techniques have the advantage of eliminating any presentation clutter due either to the presence of ships in the immediate area or to wave action. Offshore double beacon operations are generally limited by the lack of suitable locations for beacon placement. Landside NAFEC tests of reflector, single beacon, and double beacon operations were conducted during the period form July 1978 to February 1979. Results showed that reflectors typically could not be identified due to the presence of ground clutter, while beacon mode identification was generally very successful. During the double beacon testing, beacon separation was included as a controlled variable, with one beacon permanently positioned at the target landing zone and the other positioned in line with the final approach course at varying distances beyond the first. Operational evaluation of the double beacon technique concluded that:

1) It is difficult for the pilot to determine the actual target locations such that he can construct an imaginary "intended course line" between the targets, and then acquire that course. This results since the targets paint a wide return (10°-15°), and since each target arc is centered around the display origin, which tends to indicate that the targets are in proper alignment when they actually are not (see Figure 9.1).

2) It was found that even at moderate separations, it was often not possible to adjust gain such that either the

far target was not lost, or the near target would not expand and break up with sidelobe returns. This effect was partially compensated for in later tests by reducing the gain of the near beacon by 3 dB.

It was later discovered that the STC circuit in the radar system was improperly adjusted and could be the possible cause of the problem. Several double beacon flights flown later in the program verified this fact to some degree. Further analysis of the double beacon data is underway to determine the resulting degree of improvement to tracking accuracy.

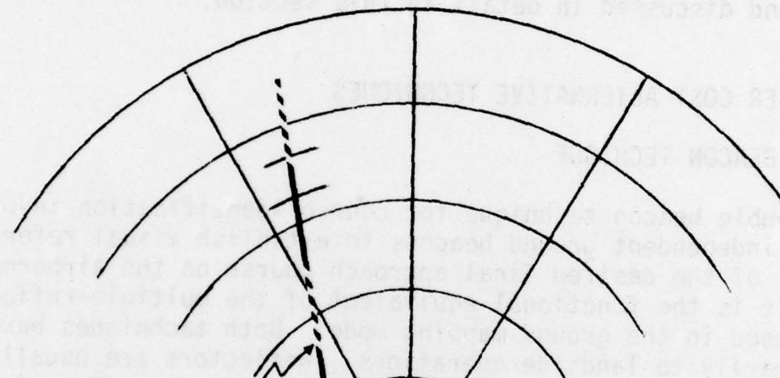


Figure 9.1 Double Beacon Technique

B. DOUBLE-PULSED BEACON TECHNIQUE

The double-pulsed beacon technique is simply a modification of the double beacon technique described previously. The beacon located at the missed approach point is modified to emit a time-separated double pulse, thereby establishing three returns on the airborne display. A typical display is shown in Figure 9.2. Although the triple return facilitaties a more accurate estimation of the desired relative aircraft position, this technique suffers from the same limitations found in the double beacon technique. Until these fundamental problems are resolved, testing of the double-pulsed beacon technique is not planned.

C. HEADING ERROR CURSOR TECHNIQUE

The heading error cursor technique is based on a minor airborne system modification which relates radar return information directly to both aircraft present position and desired final approach course. It works equally well in both the landside and offshore environment and imposes no special requirements on ground beacons or reflectors. The minor modification required amounts to the generation on the radar screen

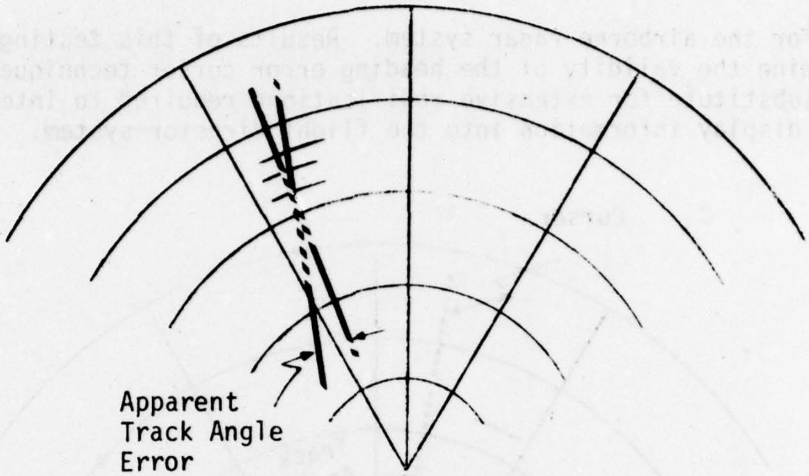


Figure 9.2 Double-Pulse Beacon Technique

of an additional azimuth cursor displaying the intended approach course bearing relative to aircraft heading. In a no-wind situation, if the aircraft is on the final approach course and tracking it, the error cursor would be in the 0° azimuth position and the target return would fall underneath it. If the aircraft was off course to the right but the current heading coincided with the desired final approach course, the cursor would still be at 0° azimuth but the target return would be off to the left. If, from this position, the aircraft established a heading directly to the target, the return would be at 0° azimuth but the error cursor would be off to the right. In general terms, the cursor represents a path parallel to the desired approach path. Once the pilot maneuvers the aircraft onto the proper approach course, the error cursor will split the return. When the cursor does not intersect the return, the aircraft is off course and the angular difference between the target center and the cursor is equal to track angle error. This provides navigational data directly to the pilot. Figure 9.3 displays a typical off-course indication while Figure 9.4 shows the effect of drift on an on-course and tracking display. Two rules of thumb can be emphasized when using this technique. Both apply to a no-wind situation, but with application of proper drift angle logic, will apply to any situation:

1) The target return should be kept between the error cursor and the 0° azimuth mark. This will insure interception of the desired final approach course prior to the missed approach point. The greater the angular distance between the return and the 0° azimuth mark the sooner the approach course will be intercepted.

2) Turning in the direction corresponding to the direction from the error cursor to the target return will insure the proper direction of turn for course correction.

The NAFEC implementation of this tecnique, to be tested in the near future, utilizes HSI system inputs to formulate heading error synchro

data for the airborne radar system. Results of this testing will determine the validity of the heading error cursor technique as a low cost substitute for extensive modifications required to integrate the radar display information into the flight director system.

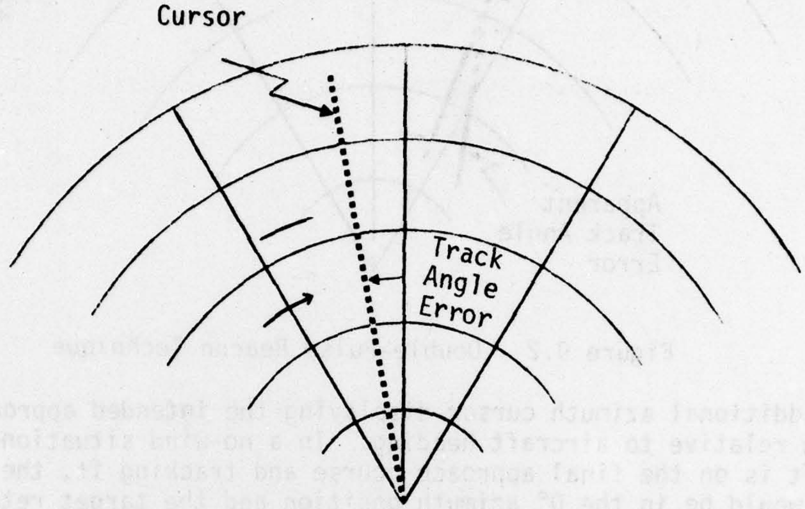
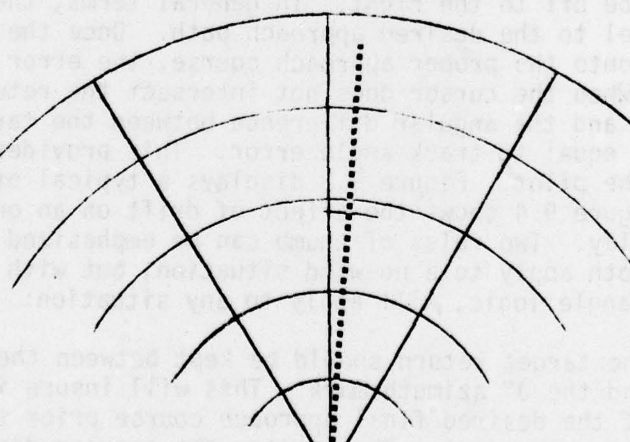


Figure 9.3 Heading Cursor Technique (Off-Course)



Figue 9.4 Heading Cursor Technique (On-Course)

9.2 COMBINED BEACON/MAPPING MODE

The impetus of this study to date has dictated the analysis of the radar display modes, beacon and ground mapping, as separate entities. The test series to be implemented in the summer of '79 will include the collection of data from a combined beacon and ground mapping display. Functionally this concept has several advantages but there are some basic operational questions which have to be answered. The presentation itself is simply a beacon overlay on a ground mapping display. Theoretically, this combines the advantages of both a beacon display (primarily discrete identification of a single point on the earth's surface regardless of whether that point is truly radar significant) and the ground mapping display (primarily presentation of the surrounding environment providing clues for aircraft positioning and possible terrain obstruction conflicts). Of major concern is the question of to what degree will the disadvantages associated with each mode be incorporated into the combined mode. For example, early in this study it was determined that the use of radar reflectors as approach aids was not feasible due to the amount of ground clutter and the associated washing out of the reflector target return. The beacon signal should be somewhat stronger and thus should present a brighter return. Whether the return will be bright enough to overcome the adverse effects of ground clutter has yet to be determined. Another consideration, most often associated with the beacon mode, is that of radar sidelobe effect. This effect has the tendency to spread the beacon return horizontally, particularly under conditions of high gain setting usually at close-in ranges. Since a mapping display generally requires slightly higher gain settings, it can be expected that radar sidelobing will have a greater effect in the combined mode than in the beacon mode.

The problems associated with the combined beacon and ground mapping mode are expected to be relatively minor and, once they are worked out the advantages to the combined mode should be significant in pilot workload and stress reduction, aircraft orientation, terrain clearance, and overall safety. As was stated earlier, this concept will be test flown during the upcoming series of tests planned (Summer, 1979). The results of these tests will be a significant input to the viability of the combined radar mode as an operational inflight approach aid.

BIBLIOGRAPHY

1. Anonymous, "Operator's Manual Bendix RDR-1300/1400 Multi-Mode Radar", Bendix Avionics Division.

2. Mackin, C.W., NAFEC Memo to Project Manager, "Test Results, Motorola X-Band Transponder", National Aviation Facilities Experimental Center (NAFEC), 28 September 1978.

3. Anonymous, "United States Standard for Terminal Instrument Procedures (TERPS)", Federal Aviation Administration, July 1976.

4. Bolz, E.H., Eisele, J.E., McConkey, E.D., "Flight Test Plan for Airborne Radar Approach Testing in CH53A Helicopter N-39 Beacon Mode", Systems Control, Inc. (Vt), Champlain Technology Industries Division, September 1978.

5. Mackin, C.W., NAFEC Memo to Project Manager, "A Brief Summary of ARA Reflector Flights to Date", National Aviation Facilities Experimental Center (NAFEC), 14 August 1978.

6. Special Committee 133, "Minimum Operational Performance Standard for Airborne Radar Approach and Beacon Systems for Helicopters", Radio Technical Commission for Aeronautics (RTCA), RTCA Paper No. 211-78/SC133-61, 22 September 1978.